Seismic Analysis of High-Rise Building

by

Response Spectrum Method

A THESIS SUBMITTED IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE OF

BACHELOR OF TECHNOLOGY
IN
CIVIL ENGINEERING

By

Sweta Swagatika Dash
111CE0031

Under the guidance of
Prof. K.C. Biswal

Department of Civil Engineering

National Institute of Technology Rourkela- 2015

Certificate

This is to certify that the project entitled "**Seismic Analysis of High- Rise Building by Response Spectrum Method"** submitted by **Ms. Sweta Swagatika Dash** [Roll No. 111CE0031] in partial fulfilment of the requirements for the award of Bachelor of Technology degree in Civil Engineering at the National Institute of Technology Rourkela (Deemed University) is an authentic work carried out by her under my supervision and guidance.

To the best of my knowledge the matter embodied in the project has not been submitted to any other university/institute for the award of any degree or diploma.

.

Date: 11 May 2015.

Prof. K.C.Biswal
Department of Civil Engineering
National Institute of Technology
Rourkela- 769008

Acknowledgement

I am extremely grateful to my project guide Prof K.C. Biswal for giving me the opportunity to work under him. I would like to acknowledge my deepest gratitude and appreciation to him for his invaluable guidance, constant encouragement and unparalleled knowledge about the subject during the entire course of project work.

I would also like to express my gratefulness to Prof R. Davis and Prof P. Sarkar for their help and valued inputs and suggestions.

I would also like to acknowledge my gratitude to all the faculty members and staff of Civil Engineering Department, National Institute of Technology Rourkela, for their relentless efforts to impart knowledge in the field of Civil Engineering as well as life and helping us come all the way in these four years.

Sweta Swagatika Dash

111CE0031

B.Tech 8th Semester

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figures	Page No.

ABSTRACT

Reinforced Concrete Frames are the most commonly adopted buildings construction practices in India. With growing economy, urbanisation and unavailability of horizontal space increasing cost of land and need for agricultural land, high-rise sprawling structures have become highly preferable in Indian buildings scenario, especially in urban. With high-rise structures, not only the building has to take up gravity loads, but as well as lateral forces. Many important Indian cities fall under high risk seismic zones, hence strengthening of buildings for lateral forces is a prerequisite. In this study the aim is to analyze the response of a high-rise structure to ground motion using Response Spectrum Analysis. Different models, that is, bare frame, brace frame and shear wall frame are considered in Staad Pro. and change in the time period, stiffness, base shear, storey drifts and top-storey deflection of the building is observed and compared.

INTRODUCTION

Earthquake has always been a threat to human civilization from the day of its existence, devastating human lives, property and man-made structures. The very recent earthquake that we faced in our neighbouring country Nepal has again shown nature's fury, causing such a massive destruction to the country and its people. It is such an unpredictable calamity that it is very necessary for survival to ensure the strength of the structures against seismic forces. Therefore there is continuous research work going on around the globe, revolving around development of new and better techniques that can be incorporated in structures for better seismic performance. Obviously, buildings designed with special techniques to resist damages during seismic activity have much higher cost of construction than normal buildings, but for safety against failures under seismic forces it is a prerequisite.

Earthquake causes random ground motions, in all possible directions emanating from the epicentre. Vertical ground motions are rare, but an earthquake is always accompanied with horizontal ground shaking. The ground vibration causes the structures resting on the ground to vibrate, developing inertial forces in the structure. As the earthquake changes directions, it can cause reversal of stresses in the structural components, that is, tension may change to compression and compression ma change to tension. Earthquake can cause generation of high stresses, which can lead to yielding of structures and large deformations, rendering the structure non-functional and unserviceable. There can be large storey drift in the building, making the building unsafe for the occupants to continue living there.

Reinforced Concrete frames are the most common construction practices in India, with increasing numbers of high-rise structures adding up to the landscape. There are many important Indian cities that fall in highly active seismic zones. Such high-rise structures, constructed especially in highly prone seismic zones, should be analyzed and designed for ductility and should be designed with extra lateral stiffening system to improve their seismic performance and reduce damages. Two of the most commonly used lateral stiffening systems that can be used in buildings to keep the deflections under limits are bracing system and shear walls

The use of steel bracing system is a viable option for retrofitting a reinforced concrete frame for improved seismic performances. Steel braces provide required strength and stiffness, takes up less space, easy to handle during construction, can also be used as architectural element and is economic. Steel braces are effective as they take up axial stresses and due to their stiffness, reduce deflection along the direction of their orientation.

Fig.1 RC building with exterior bracing system as lateral stiffener [1]

Fig.2 Connection of steel brace to concrete member [2]

Shear wall is a vertical member that can resist lateral forces directed along its orientation. Shear walls are structural system consisting of braced panels, also known as Shear Panels. Concrete Shear walls are widespread in many earthquake-prone countries like Canada, Turkey, Romania, Colombia, Russia. It has been in practice since 1960's, used in buildings ranging from medium- to high-rise structures. Shear walls should always be placed symmetrically in the structure and on each floor, including the basement. Reinforced concrete Shear walls transfer seismic forces to foundation and provide strength and stiffness.

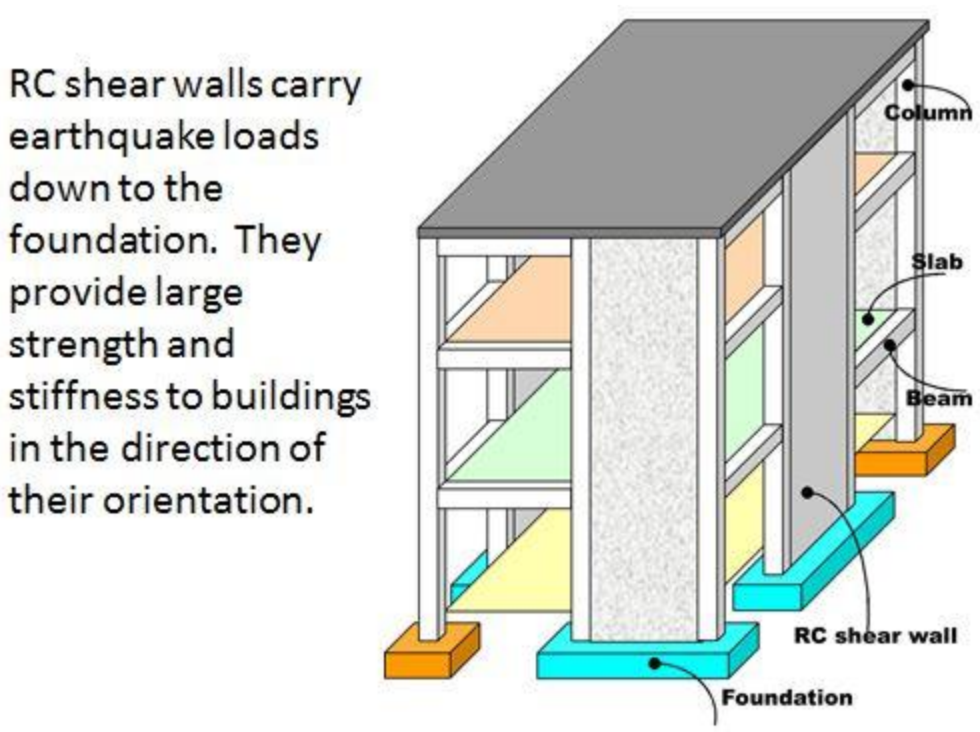


Fig3. Building showing a Shear Wall [3]

OBJECTIVES

The objectives of present work are as follows:

a) To analyze the building with different ground motions, namely, IS code compatible ground motion, Imperial Valley ground motion and San Francisco ground motion.

b) To perform dynamic analysis of the building using response spectrum method.

c) To model building with different lateral stiffness systems and study the change in response of the building

d) To compare and get a better and efficient lateral stiffness system

SCOPE

a) This study concerns analysis of reinforced concrete moment resisting open frame , open frame with braces and open frame with shear walls only, using Staad Pro program. The effect of brick infill is ignored.

b) This study involves a theoretical 12 storey building with normal floor loading and no infill walls.

c) The comparison of fundamental period, base shear, inter-storey drift and top-storey deflection is done by using Response Spectrum analysis, which is a linear elastic analysis

LITERATURE REVIEW

Chandurkar, Pajgade (2013) evaluated the response of a 10 storey building with seismic shear wall using ETAB v 9.5. Main focus was to compare the change in response by changing the location of shear wall in the multi-storey building. Four models were studied-one being a bare frame structural system and rest three were of dual type structural system. The results were excellent for shear wall in short span at corners. Larger dimension of shear wall was found to be ineffective in 10 or below 10 stories. Shear wall is an effective and economical option for high-rise structures. It was observed that changing positions of shear wall was found to attract forces, hence proper positioning of shear wall is vital. Major amount of horizontal forces were taken by shear wall when the dimension is large. It was also observed that shear walls at substantial locations reduced displacements due to earthquake.

Viswanath K.G (2010) investigated the seismic performance of reinforced concrete buildings using concentric steel bracing. Analysis of a four, eight, twelve and sixteen storied building in seismic zone IV was done using Staad Pro software, as per IS 1893: 2002 (Part-I). The bracing was provided for peripheral columns, and the effectiveness of steel bracing distribution along the height of the building, on the seismic performance of the building was studied. It was found that lateral displacements of the buildings reduced after using X-type bracings. Steel bracings were found to reduce flexure and shear demand on the beams and columns and transfer lateral load by axial load mechanism. Building frames with X- type bracing were found to have minimum bending as compared to other types of bracing. Steel bracing system was found to be a better alternative for seismic retrofitting as they do not increase the total weight of the building significantly.

Chavan, Jadhav (2014) studied seismic analysis of reinforced concrete with different bracing arrangements by equivalent static method using Staad Pro. software. The arrangements considered were diagonal, V-type, inverted V-type and X-type. It was observed that lateral displacement reduced by 50% to 60% and maximum displacement reduced by using X-type bracing. Base shear of the building was also found to increase from the bare frame, by use of X-type bracing, indicating increase in stiffness.

Esmaili et al. (2008) studied the structural aspect of a 56 stories high tower, located in a high seismic zone in Tehran. Seismic evaluation of the building was done by non-linear dynamic analysis. The existing building had main walls and its side walls as shear walls, connected to the main wall by coupling of beams. The conclusion was to consider the time-dependency of concrete. Steel bracing system should be provided for energy absorption for ductility, but axial load can have adverse effect on their performance. It is both conceptually and economically unacceptable to use shear wall as both gravity and bracing system. Confinement of concrete in shear walls is good option for providing ductility and stability.

Akbari et al. (2015) assessed seismic vulnerability of steel X-braced and chevron-braced Reinforced Concrete by developing analytical fragility curve. Investigation of various parameters like height of the frame, the p-delta effect and the fraction of base shear for the bracing system was done. For a specific designed base shear, steel-braced RC dual systems have low damage probability and larger capacity than unbraced system. Combination of stronger bracing and weaker frame reduces the damage probability on the entire system. Irrespective of height of the frame, Chevron braces are more effective than X-type bracing. In case of X-type bracing system, it is better to distribute base shear evenly between the braces and the RC frame, whereas in case of Chevron braced system it is appropriate to allocate higher value of share of base shear to the braces. Including p-delta effect increases damage probability by 20% for shorter dual system and by 100% for taller dual systems. The p-delta effect is more dominant for smaller PGA values.

Kappos , Manafpour (2000) presented new methodology for seismic design of RC building based on feasible partial inelastic model of the structure and performance criteria for two distinct limit states. The procedure is developed in a format that can be incorporated in design codes like Eurocode 8. Time-History (Non-linear dynamic) analysis and Pushover analysis (Non-linear Static analysis) were explored. The adopted method showed better seismic performance than standard code procedure, at least in case of regular RC frame building. It was found that behaviour under "life-safety" was easier to control than under serviceability earthquake because of the adoption of performance criteria involving ductility requirements of members for "life-safety" earthquake.

Yamada et al. studied, experimentally as well as analytically, deformation and fracture characteristics of lateral load resisting systems-shear wall for RC frame- and –steel bracing for steel multi-storey frame- under earthquake, considering models having 3 different spans and 3, 6 and 9 storeys. Deformations and facture results for all the three cases are compared and differences are clarified by normalization of proposed horizontal resisting ratios.

RESEARCH METHODOLOGY

1. LITERATURE REVIEW

To gather various types of work on seismic analysis of high-rise structures and increasing lateral stiffness of the system various papers, thesis and research articles were studied thoroughly and referred. The idea behind doing literature review was to collect data and have understanding on different methods and approaches that can be used, to clear understand the software requirement of the project. Literature review was done to have a thorough guidelines during the entire project work.

2. DATA COLLECTION

Various Indian standard codes were collected from the department of civil engineering NIT Rourkela. The earthquake data's were obtained from the site Peer.berkeley.edu. The earthquakes considered in this work are time history of ground motion as per IS 1893:2002 (Part-I), Imperial Valley and San Francisco.

3. METHODOLOGY ADOPTED

As discussed in the scope of the work, the entire work is divided into three parts:

- Analysis of bare frame in all the above three mentioned ground motions
- Analysis of the braced frames.
- Analysis of the frame with shear wall

For analysis a 12 stories high building is modeled in Staad Pro as a space frame. The building is does not represent any real existing building. The building is unsymmetrical with the span more along Z direction than along X direction. The building rises up to 42m along Y direction and spans 15m along X direction and 20 m along Z direction .The building is analyzed by Response Spectrum Analysis, which is a linear dynamic analysis. Dynamic Analysis is adopted since it gives better results than static analysis. The specifications of the frame are given in Table 1. and the plan and the model of the building is shown in Fig. 4 and

Fig.5 respectively. In the entire course work X and Z are taken as the horizontal axes and Y as the vertical axes.

Table 1. Specifications of the building

Specfications	**Data**
Storey Height	3.5m
No. of bays along X direction	3
No. of bays along X direction	4
Bay Length along X direction	5m
Bay Length along Z direction	5m
Concrete grade used	M 30
Columns	0.45m X 0.25m
Longitudinal Beams	0.40m X 0.25m
Transverse Beams	0.35m X 0.25m
Slab Thickness	0.1m
Unit Weight of Concrete	25 kN/m3
Live Load	3.5 kN/m3
Zone	IV
Soil Conditions	Hard Soil
Damping Ratio	5%

Fig. 4 Plan of the building

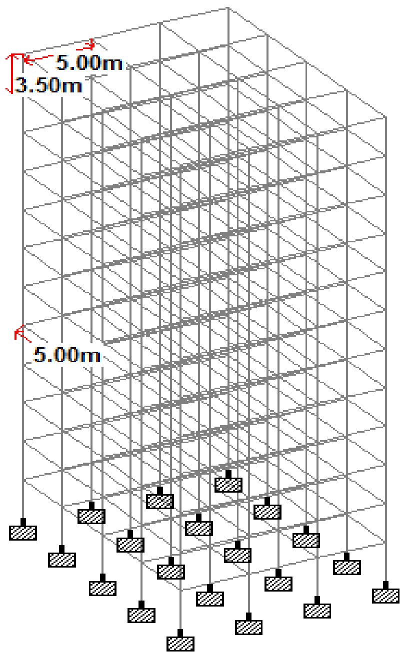


Fig. 5 Model of the building

Response Spectrum Analysis

Response Spectrum is a linear dynamic analysis. Response spectrum is a plot of the maximum response of a SDOF system to a ground motion versus time period. It is derived from time history analysis of ground motion by taking the maximum response for each time period.

The time periods of the bare frame up to 12th mode calculated from MATLAB program is given below in Table 2.

Table 2. Time period of bare frame

Mode	Time Period (s)
1	2.4297
2	0.8145
3	0.4943
4	0.3592
5	0.286
6	0.2409
7	0.2112

8	0.1909
9	0.1769
10	0.1674
11	0.1613
12	0.1579

As given in IS 1893-2002 (Part-I), fundamental natural time period of a RC building without brick infill is given by :

7.6 Fundamental Natural Period

7.6.1 The approximate fundamental natural period of vibration (T_a), in seconds, of a moment-resisting frame building without brick infil panels may be estimated by the empirical expression:

$T_a = 0.075\, h^{0.75}$ for RC frame building

$= 0.085\, h^{0.75}$ for steel frame building

where

h = Height of building, in m. This excludes the basement storeys, where basement walls are connected with the ground floor deck or fitted between the building columns. But, it includes the basement storeys, when they are not so connected.

So, by IS code time period of the bare frame = 1.237 s

In Staad Pro, Response Spectrum Analysis is done as follows:

1. After preparing the bare model, seismic definition for IS 1893-2002 was created by giving the required input of time period, zone factor, R factor, etc. Then under seismic definition self-weight and floor weights of 2.5kN/m2 and 3.5 kN/m2 were given.
2. Under Load Definition Earthquake load, Dead load, Live load and various load combinations were created.
3. Under Earthquake load, after assigning self-weight, floor load and live load in X, Y and Z directions, Response Spectra was defined. For Indian Code compatible earthquake already defined IS 1893-2002 is chosen. For Imperial Valley Earthquake and San Francisco Earthquake the response spectrum values are entered. Acceleration values for the corresponding time periods of the building for Imperial Earthquake and San Francisco earthquake has been taken by multiplying 9.81* Sa/g of their respective response spectrum. The Sa/g is the response spectrum values that were taken from the

results of MATLAB program for generating Response Spectrum from time history of ground motion of the earthquake considered. The time period and their corresponding acceleration values are given in the tables below.

Table 3. Time period vs. Acceleration for Imperial Ground Motion

Time Period (s)	Sa/g	Acceleration= 9.81 * Sa/g
2.4297	1.61E+00	1.58E+01
0.8145	2.31E+00	2.27E+01
0.4943	2.14E+00	2.10E+01
0.3592	1.47E+00	1.44E+01
0.286	2.11E+00	2.07E+01
0.2409	1.89E+00	1.85E+01
0.2112	1.47E+00	1.44E+01
0.1909	1.10E+00	1.08E+01
0.1769	1.12E+00	1.10E+01
0.1674	9.86E-01	9.67E+00
0.1613	8.31E-01	8.15E+00
0.1579	7.78E-01	7.64E+00

Table 4. Time period vs. Acceleration for San Francisco Ground Motion

Time Period (s)	Sa/g	Acceleration= 9.81 * Sa/g
2.4297	1.03E+00	1.01E+01
0.8145	1.20E+00	1.18E+01
0.4943	1.23E+00	1.21E+01
0.3592	2.09E+00	2.05E+01
0.286	3.13E+00	3.07E+01
0.2409	2.90E+00	2.85E+01
0.2112	2.12E+00	2.08E+01
0.1909	1.68E+00	1.64E+01
0.1769	1.63E+00	1.60E+01
0.1674	1.98E+00	1.94E+01
0.1613	2.28E+00	2.24E+01
0.1579	2.47E+00	2.42E+01

4. The load combinations that were considered were according to IS 1893-2002 (Part-1) and are as follows:

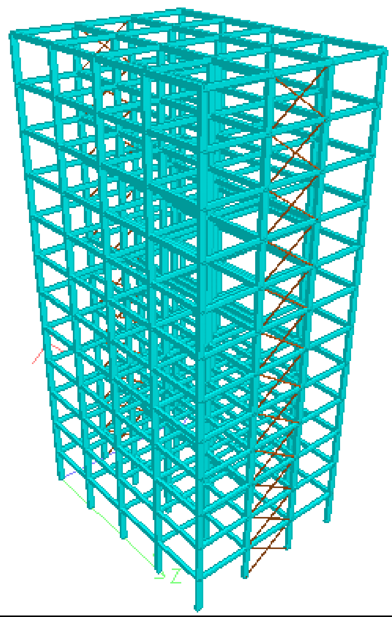
    1.5(DL+LL)
    1.2 (DL+ LL+EL)
    1.2 (DL+ LL-EL)
    1.5 (DL+EL)
    1.5 (DL-EL)
    0.9DL + 1.5 EL
    0.9DL -1.5 EL

MODELING OF BRACED FRAME

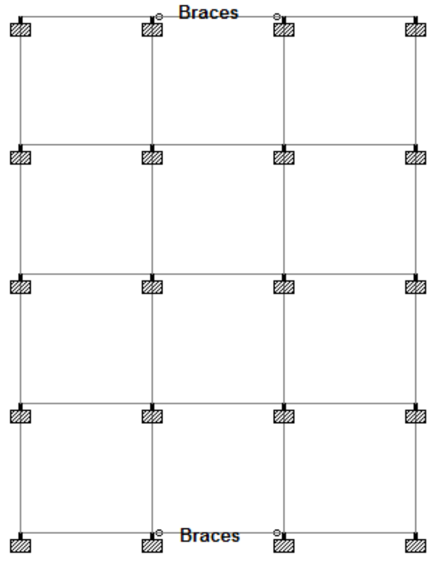
For braces angle section ISA 60 X 40 X 6 is used. There are four trial locations in the building where braces are placed and analyzed for their effect on lateral stiffness. Braces are modeled as axial force members having pinned end connections. Bracings are of X-type modeled throughout the height of the building. The four locations are as follows:

Location 1: Bracing A- at the exterior side of the frame along X-direction.
Location 2: Bracing B- at the exterior side of the frame along Y-direction.
Location 3: Bracing AB- at the exterior side of the frame along X and Y-direction.
Location 4: Bracing C- at the exterior side of the frame around the corners.

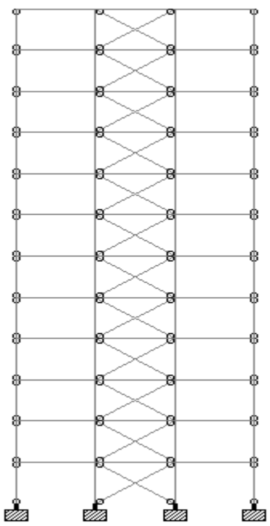
The figures of the models with different locations of braces are given in the tables below:



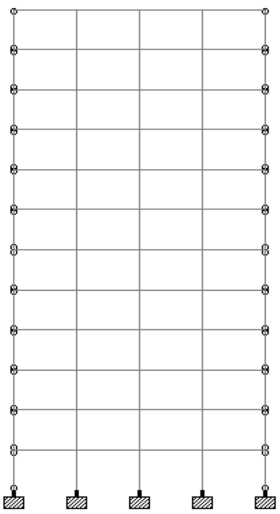
3D Model of the building with braces at location 1



Plan of the building



Elevation in X-Y Plane



Elevation in Y-Z Plane

Table 5. Bracings at Location 1 (Bracing A)

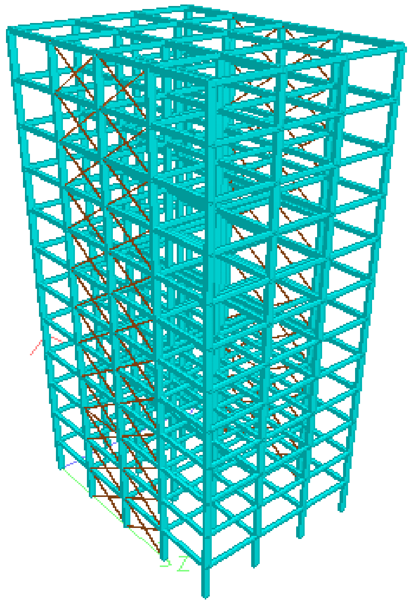
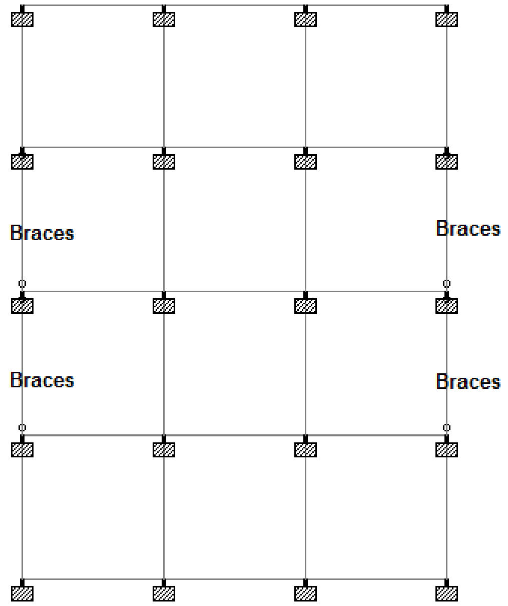
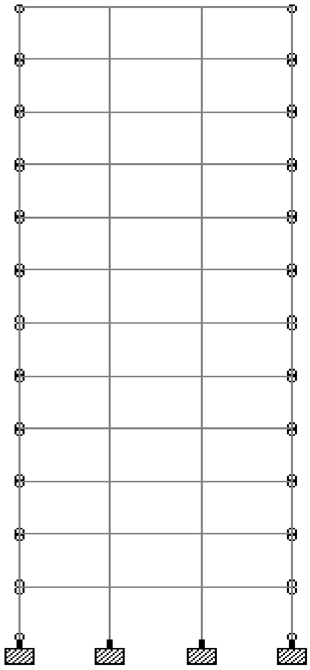
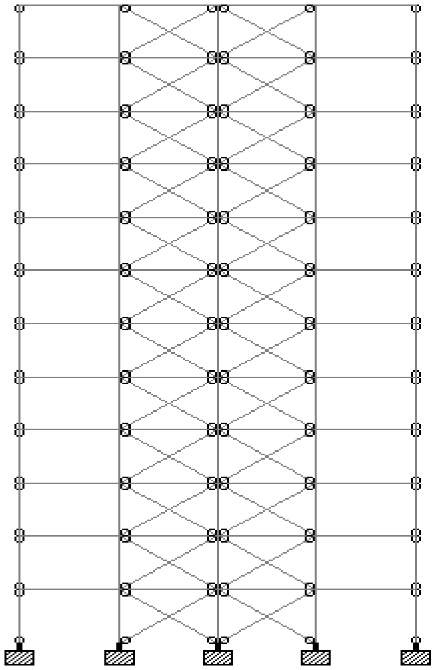
 3D Model of the building with braces at location 2	 Plan of the building
 Elevation in X-Y Plane	 Elevation in Y-Z Plane

Table 6. Bracings at Location 2 (Bracing B)

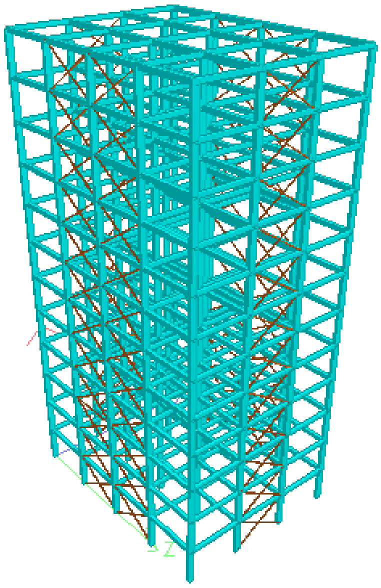
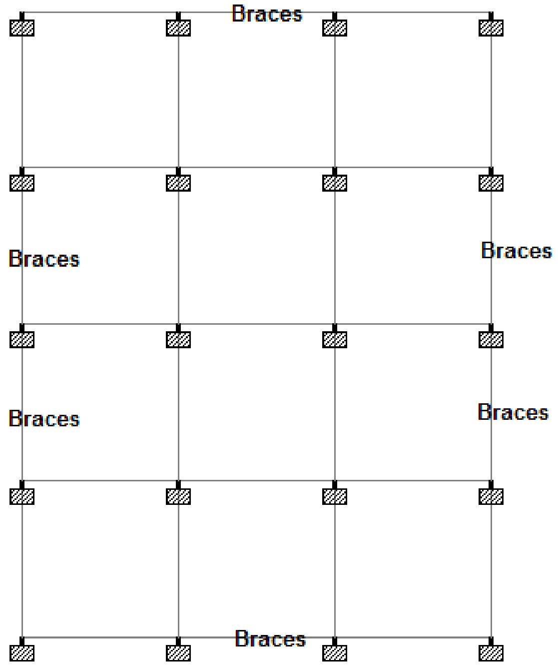
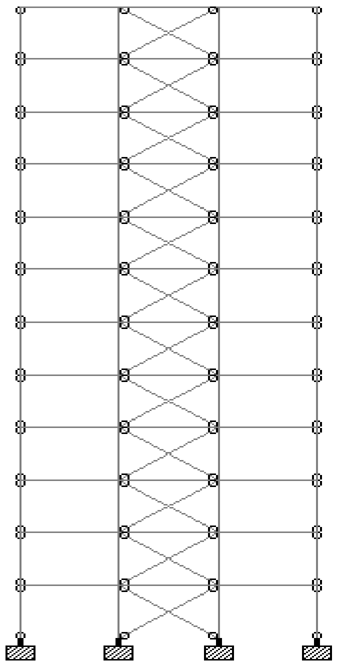
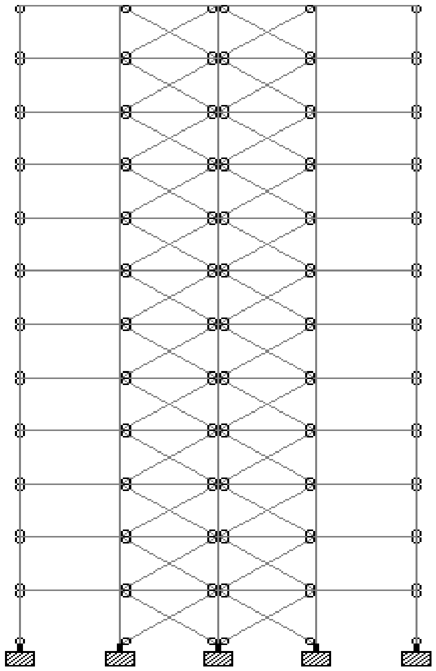
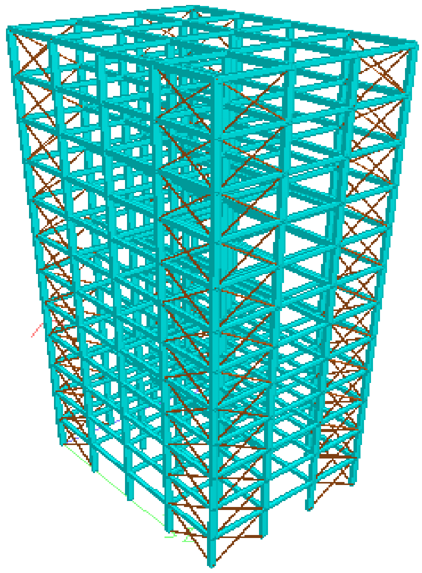
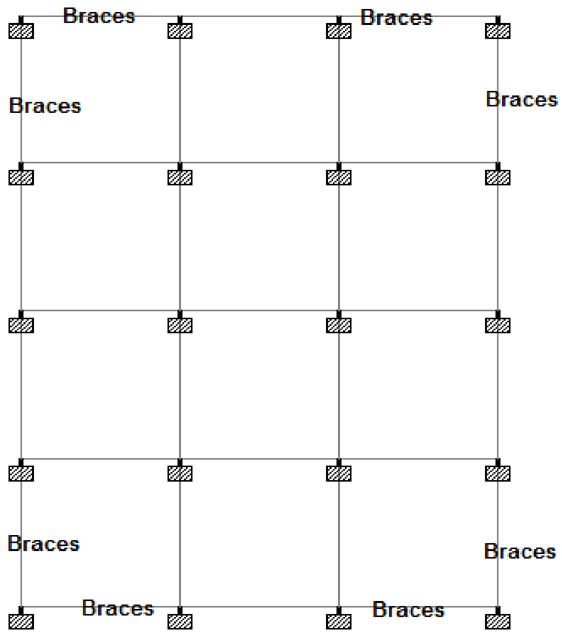
 3D Model of the building with braces at location 3	 Plan of the building
 Elevation in X-Y Plane	 Elevation in Y-Z Plane

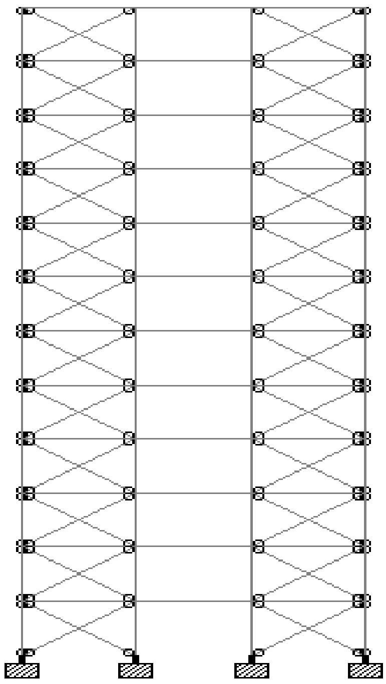
Table 7. Bracings at Location 3 (Bracing AB)



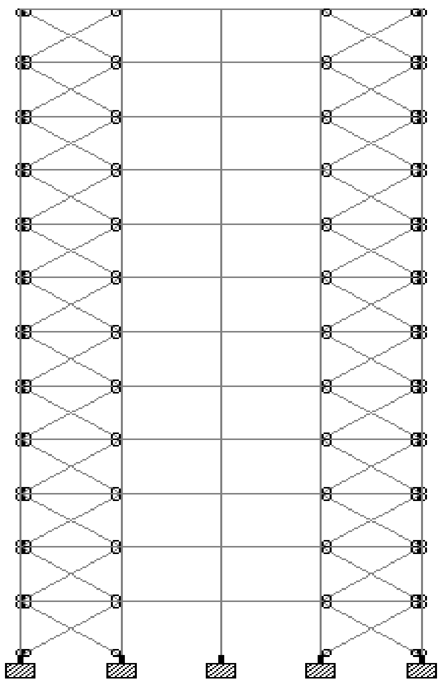
3D Model of the building with braces at location 4



Plan of the building



Elevation in X-Y Plane



Elevation in Y-Z Plane

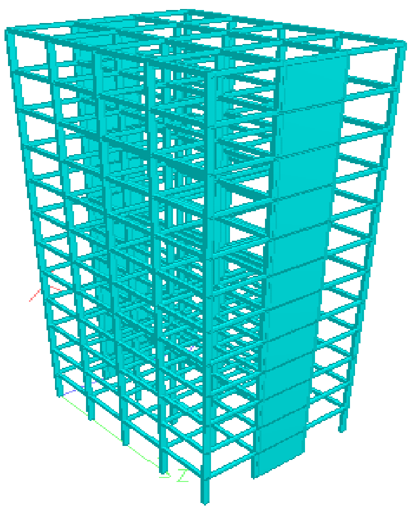
Table 8. Bracings at Location 4 (Bracing C)

MODELING OF SHEAR WALL FRAME

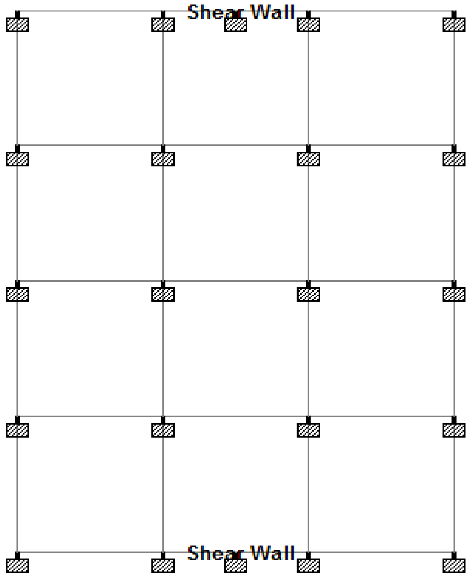
Shear Wall considered is of 250mm thickness, and placed along the entire height of the structure. Shear wall has been modelled as rectangular column section by increasing width to 5m i.e, the spacing between two columns. The shear walls are placed in the exact locations as that of bracings, and the analysis is done.

The four locations are as follows:

Location 1: Shear wall A- at the exterior side of the frame along X-direction.
Location 2: Shear wall B - at the exterior side of the frame along Y-direction.
Location 3: Shear wall AB- at the exterior side of the frame along X and Y-direction.
Location 4: Shear wall C- at the exterior side of the frame around the corners.
The figures of the models with different locations of shear walls are given below :



3D Model of the building with shear wall at location 1



Plan of the building

Table 9. Shear Wall at Location 1 (Shear Wall A)

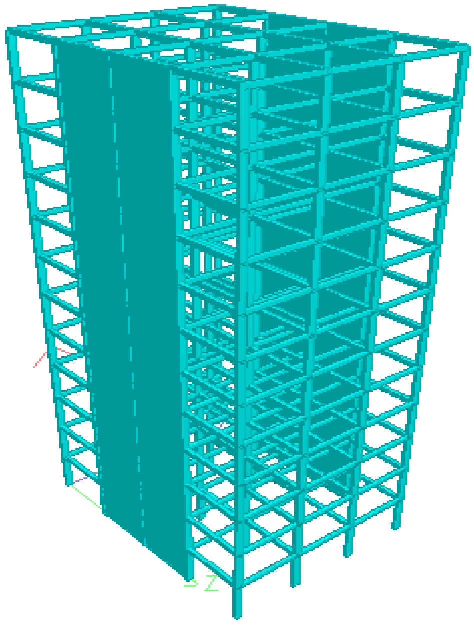
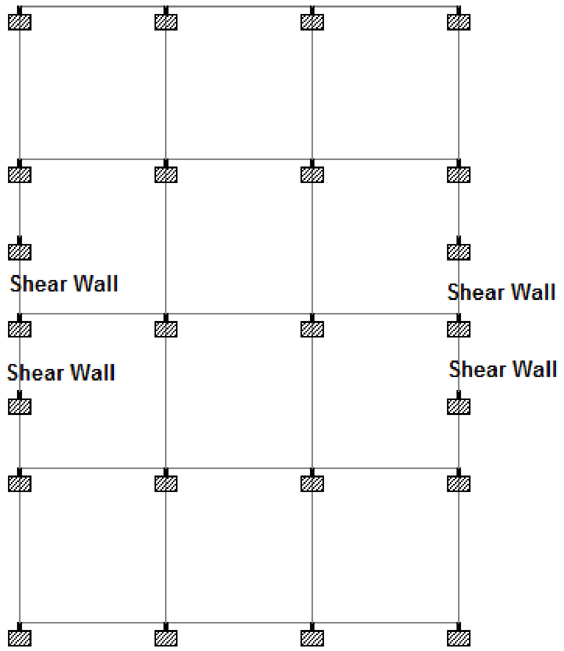
 3D Model of the building with shear wall at location 1	 Plan of the building

Table 10. Shear Wall at Location 2 (Shear Wall B)

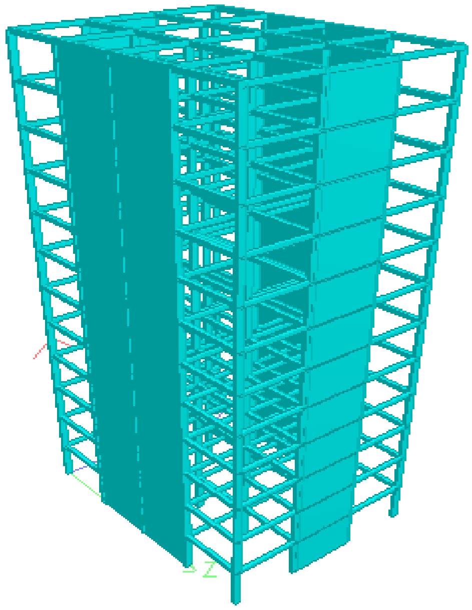
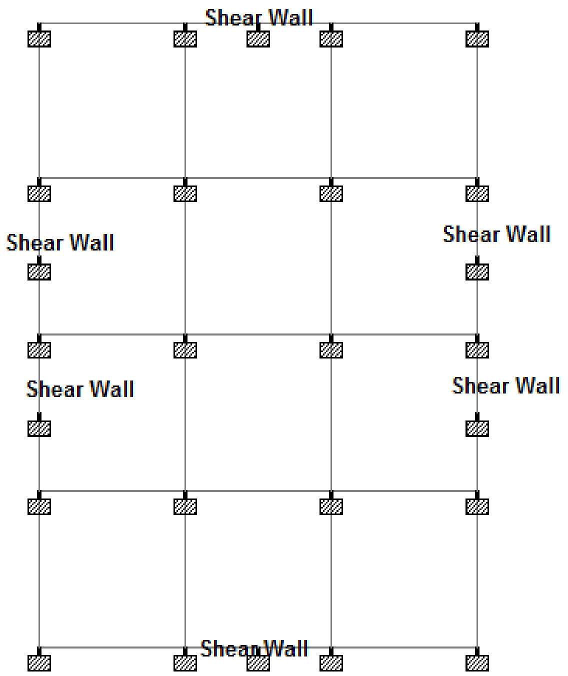
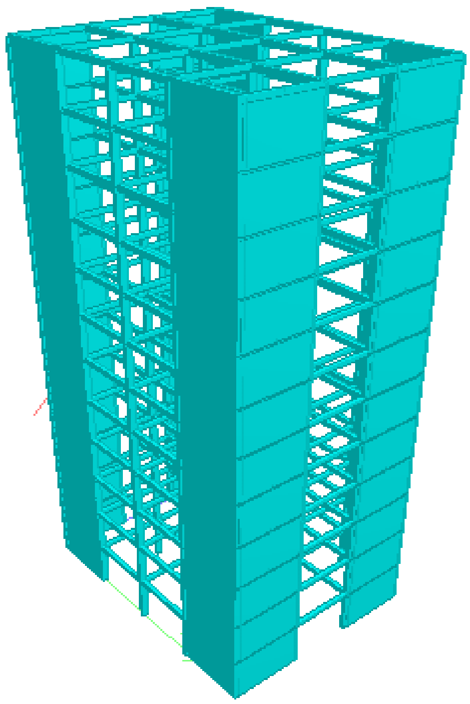
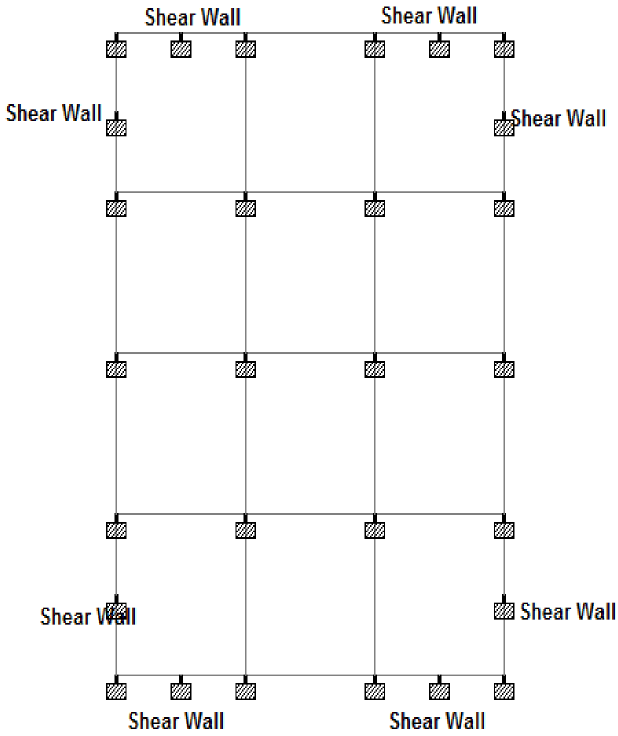
 3D Model of the building with shear wall at location 3	 Plan of the building

Table 11. Shear Wall at Location 3 (Shear Wall AB)



3D Model of the building with shear wall at location 4



Plan of the building

Table 12. Shear Wall at Location 4 (Shear Wall C)

RESULTS AND DISCUSSION

The result is based on the responses of the bare frame model and the changes in the responses after using bracings and shear wall. The results include changes in time periods, base shear, inter-storey drifts and top-storey deflections for ground motions along X and Z direction considered individually. The results of time period, base shear, inter-storey drifts and top-storey deflection for bare frame, braced frame and shear wall frame were then compared with each other and a conclusion was then drawn.

1. COMPARISON OF TIME PERIOD

In this study it was found that fundamental time period of the bare frame is longer than the time period of the braced frame and frames with shear wall. There is a gradual decrease in time period from bare frame to braced frame to frame with shear wall.

Table 13. Variation of time period

Cases	Time Period (s)
Bare Frame	3.51224
Bracing A	3.51208
Bracing B	3.53179
Bracing AB	3.53164
Bracing C	3.5124
Shear Wall A	3.59052
Shear Wall B	3.36548
Shear Wall AB	2.05164
Shear Wall C	1.70323

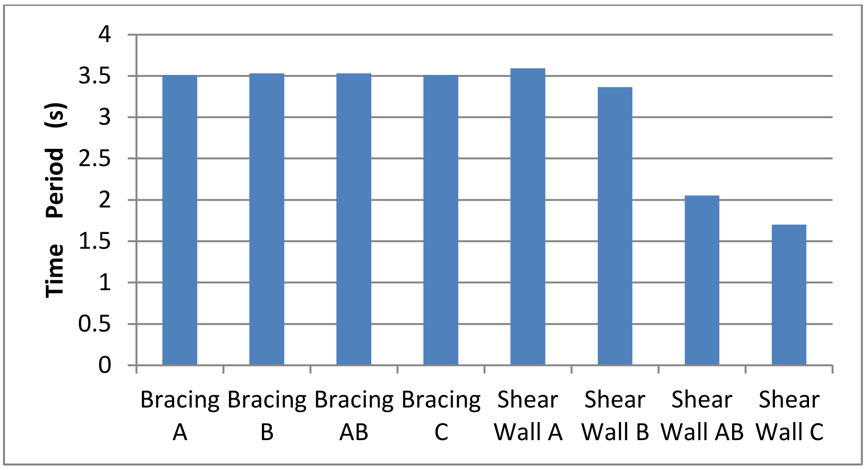


Fig.6 Variation of time periods

2. Results and Comparison for compatible time history of ground acceleration as per IS 1893-2002(Part-I)

Response Spectrum analysis of bare frame, bracing frame with all the cases and shear wall with all the cases for Indian Code compatible ground motion was done as per IS 1893-2002(Part-I) and the results for base shear, inter-storey drifts and top-storey deflections were compared.

2.1 Comparison of Base Shear for ground motion in X-direction

The base shear was found to be increasing from bare frame to braced frame and is even more for frame with shear wall. In case of braced frame highest base shear is found in case of Bracing C in X-direction. In case of shear wall base shear is highest in case of Shear wall C in X-direction. Shear wall B shows the least base shear among all the shear wall cases because in case of Shear Wall B the frame is stiffened only along Y- direction and not along Z.

Table 14 shows the base shear for ground motion in X-direction for all the cases. Fig 7. Shows the variation of the base shear

Table 14. Base shear for ground motion in X-direction

Cases	Base Shear (kN)
Bare Frame	568.86
Case A	688.48
Case B	568.32
Case AB	686.95
Case C	750.62
Shear Wall A	916.7
Shear Wall B	658.36
Shear Wall AB	990.91
Shear Wall C	1227.99

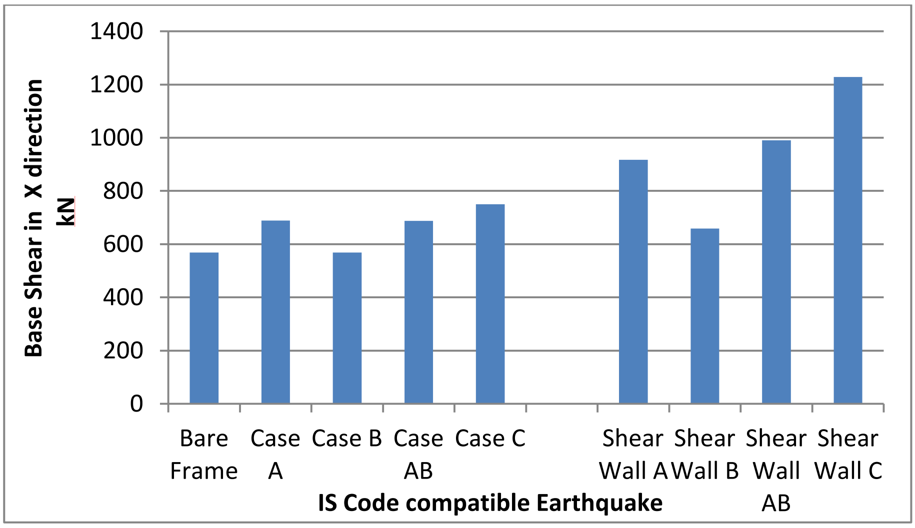


Fig 7. Variation of base shear for ground motion in X- direction

2.2 Comparison of Base Shear for ground motion in Z-direction

The base shear was found to be increasing from bare frame to braced frame and is even more for frame with shear wall. In case of braced frame highest base shear is found in case of Bracing C in Z-direction. In case of shear wall base shear is highest in case of Shear wall C in Z-direction. Shear wall A shows the least base shear among all the shear wall cases because in case of Shear Wall A the frame is stiffened only along X- direction and not along Z.

Table 15 shows the base shear for ground motion in X-direction for all the cases. Fig 8. Shows the variation of the base shear

Table 15. Base shear for ground motion in Z-direction

Cases	Base Shear (kN)
Bare Frame	525.76
Case A	525.79
Case B	522.16
Case AB	518.04
Case C	525.81
Shear Wall A	571.47
Shear Wall B	1176.35
Shear Wall AB	1207.73
Shear Wall C	1298.11

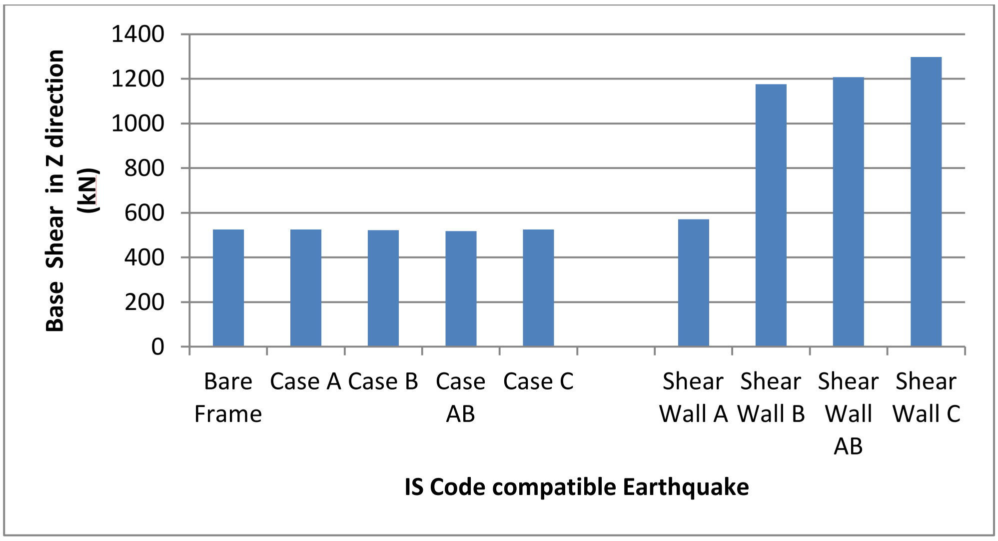


Fig 8. Variation of base shear for ground motion in Z- direction

2.3 Comparison of Inter-Storey Drift for ground motion in X-direction

As per IS 1893-2002 (Part-I) storey drift should be within 0.4% of storey height. For the building considered in this study the safe limit for storey drift is 14mm. Inter- storey drifts in bare frame was found to exceed this limit of 14mm. By using bracings and shear wall in the building the drift is found to be reduced. Inter storey drift decreases remarkably in case of shear walls. For ground motion in X-direction inter-storey drift is minimum in case of Bracing C and Shear Wall C. Shear Wall A shows the least inter-store drift in X-direction than Shear Wall B, because Shear Wall A is along X direction only whereas Shear Wall B is along Z direction only.

Table 16 shows the inter-storey drift for ground motion in Z-direction for all the cases.

Fig 9. Shows the variation of inter-storey drift.

Table 16. Inter-Storey Drift for ground motion in X- direction

Storey	Bare Frame	Bracing A	Bracing B	Bracing AB	Bracing C	Shear Wall A	Shear Wall B	Shear Wall AB	Shear Wall C
1	0	0	0	0	0	0	0	0	0
2	7.923	6.51	7.946	6.498	5.667	3.288	7.882	3.079	2.576
3	13.611	10.441	13.65	10.424	8.938	5.344	14.066	5.912	4.63
4	14.317	10.828	14.361	10.815	9.321	5.716	14.88	6.757	5.099
5	13.722	10.468	13.771	10.465	9.089	5.975	14.34	7.054	5.319
6	12.716	9.862	12.763	9.861	8.653	6.462	13.728	7.291	5.707
7	11.583	9.182	11.626	9.182	8.172	6.697	12.62	7.418	5.892
8	10.424	8.492	10.462	8.49	7.698	6.847	11.309	7.481	6.056
19	9.236	7.774	9.269	7.771	7.205	6.989	9.883	7.46	6.212
10	7.95	6.958	7.977	6.954	6.611	6.915	8.412	7.212	6.168
11	6.484	5.96	6.506	5.965	5.824	6.53	6.681	6.684	5.884
12	4.812	4.739	4.828	4.735	4.791	5.976	5.08	6.054	5.379

13	3.108	3.335	3.119	3.332	3.581	5.092	3.612	5.132	4.666

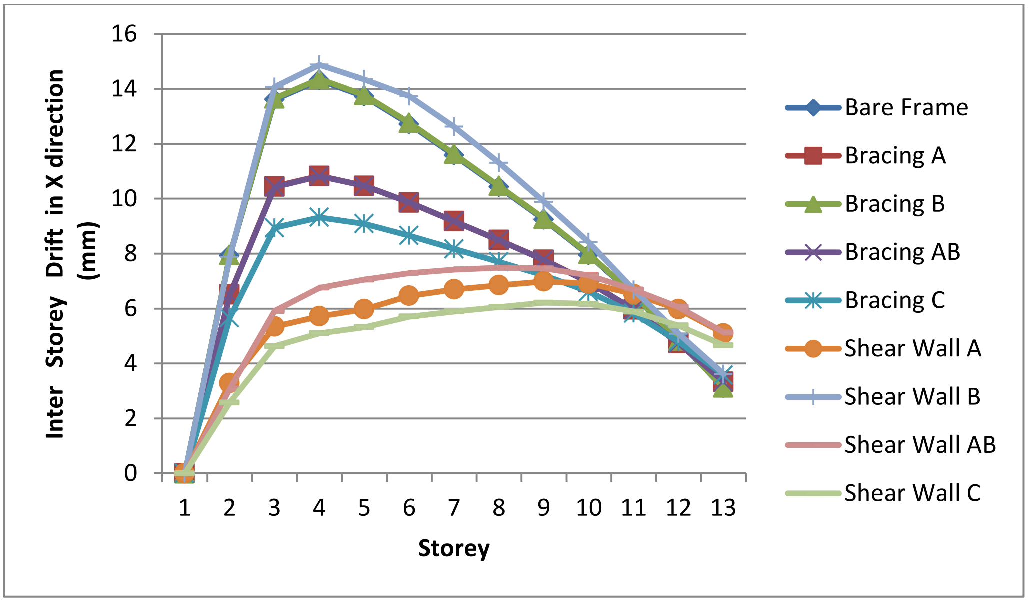


Fig 9. Variation of Inter-Storey Drift for ground motion in X direction

2.4 Comparison of Inter-Storey Drift for ground motion in Z-direction

Inter- storey drifts in bare frame was found to exceed this limit of 14mm. By using bracings it was found that there was no reduction in drift in Z direction but frame with shear wall showed remarkable reduction in the drift. Inter storey drift decreases remarkably in case of shear walls. For ground motion in Z-direction inter-storey drift is minimum in case Shear Wall C. Shear Wall B shows the least inter-store drift in Z-direction than Shear Wall A, because Shear Wall A is along Z direction only whereas Shear Wall A is along X direction only.

Table 17 shows the inter-storey drift for ground motion in Z-direction for all the cases. Fig 10. Shows the variation of inter-storey drift.

Table 17. Inter-Storey Drift for ground motion in Z- direction

Storey	Bare Frame	Bracing A	Bracing B	Bracing AB	Bracing C	Shear Wall A	Shear Wall B	Shear Wall AB	Shear Wall C
1	0	0	0	0	0	0	0	0	0
2	12.527	12.483	12.49	12.306	12.484	11.848	4.011	2.695	2.759
3	16.019	15.963	16.021	15.841	15.963	15.675	4.762	4.227	4.213
4	15.531	15.476	16.03	16.393	15.476	15.935	3.82	4.555	4.543
5	14.536	14.485	15.052	15.45	14.485	15.119	3.624	4.784	4.844
6	13.354	13.307	13.392	13.283	13.306	13.939	4.457	5.107	5.308
7	12.114	12.071	12.089	11.962	12.07	12.692	5.341	5.48	5.757
8	10.868	10.828	10.855	10.719	10.828	11.341	5.25	5.814	6.141
9	9.59	9.555	9.573	9.447	9.553	9.933	5.739	6.063	6.462
10	8.2	8.169	8.182	8.068	8.168	8.401	5.752	6.124	6.589
11	6.609	6.584	6.592	6.497	6.583	6.728	5.96	5.913	6.467
12	4.767	4.749	4.755	4.685	4.747	4.959	5.738	5.544	6.132
13	2.756	2.745	2.751	2.713	2.743	3.054	5.139	4.845	5.39

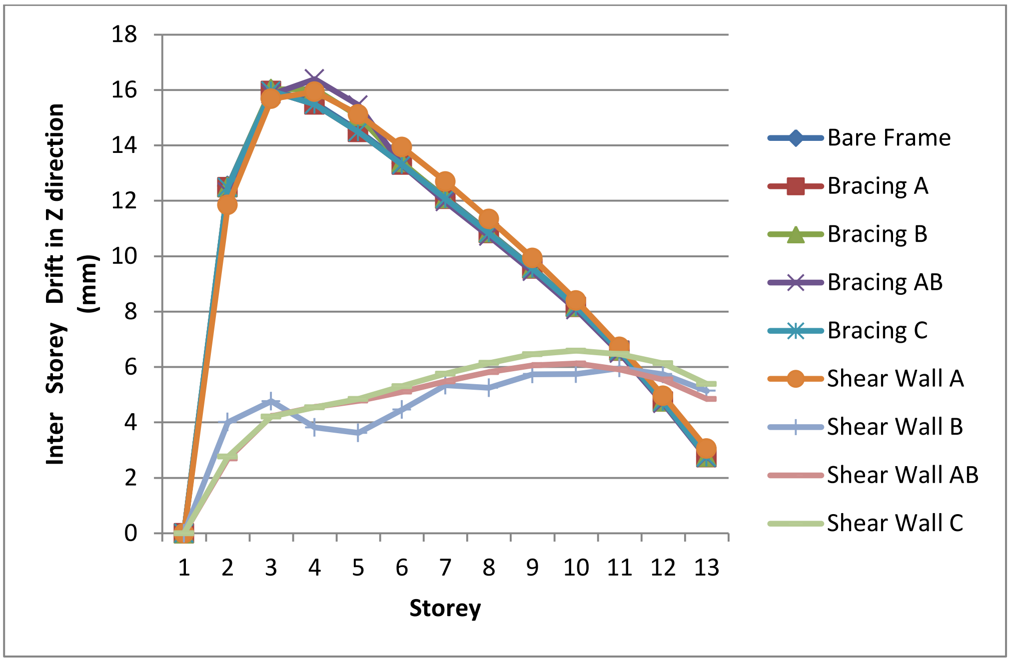


Fig 10. Variation of Inter-Storey Drift for ground motion in Z direction

2.5 Comparison of Top-Storey Deflection for ground motion in X- direction

There is reduction in top-storey deflection in the frame due to bracing and shear wall. Reduction is more in case of Bracing C and Shear Wall C. For ground motion in X- direction Shear Wall B is ineffective since in Shear Wall B case shear wall is present in Z-direction not in X-direction.

Table 18 below shows the top-storey deflection for each case, Fig 11. shows the variation in top-storey deflection in X direction and Fig.12 shows the Staad Pro results for top-storey deflection.

Table 18. Top-Storey Drift for ground motion in X- direction

Cases	Top- Storey Deflection (mm)
Bare Frame	113.876
Bracing A	90.129
Bracing B	114.571
Bracing AB	94.483
Bracing C	85.551
Shear Wall A	64.88
Shear Wall B	119.349
Shear Wall AB	67.836
Shear Wall C	53.696

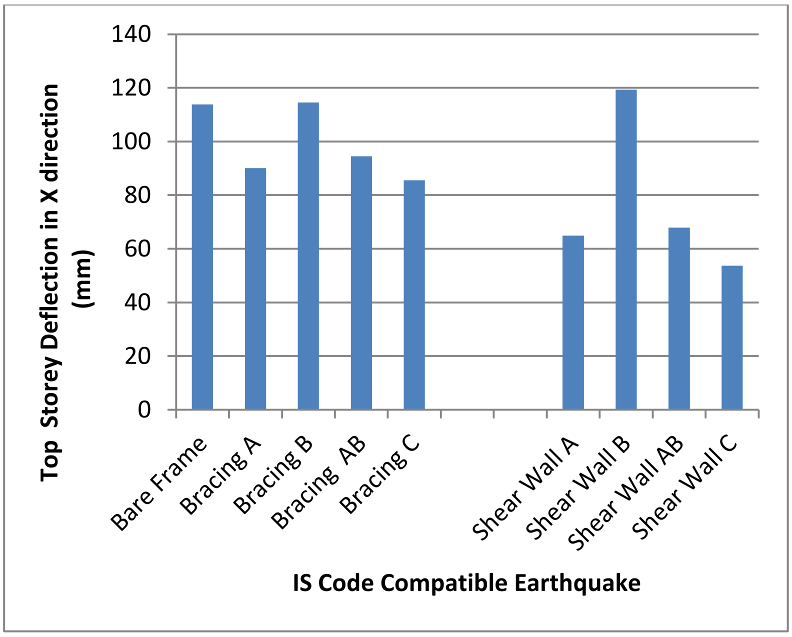


Fig 11. Variation of Top-Storey Deflection for ground motion in X direction

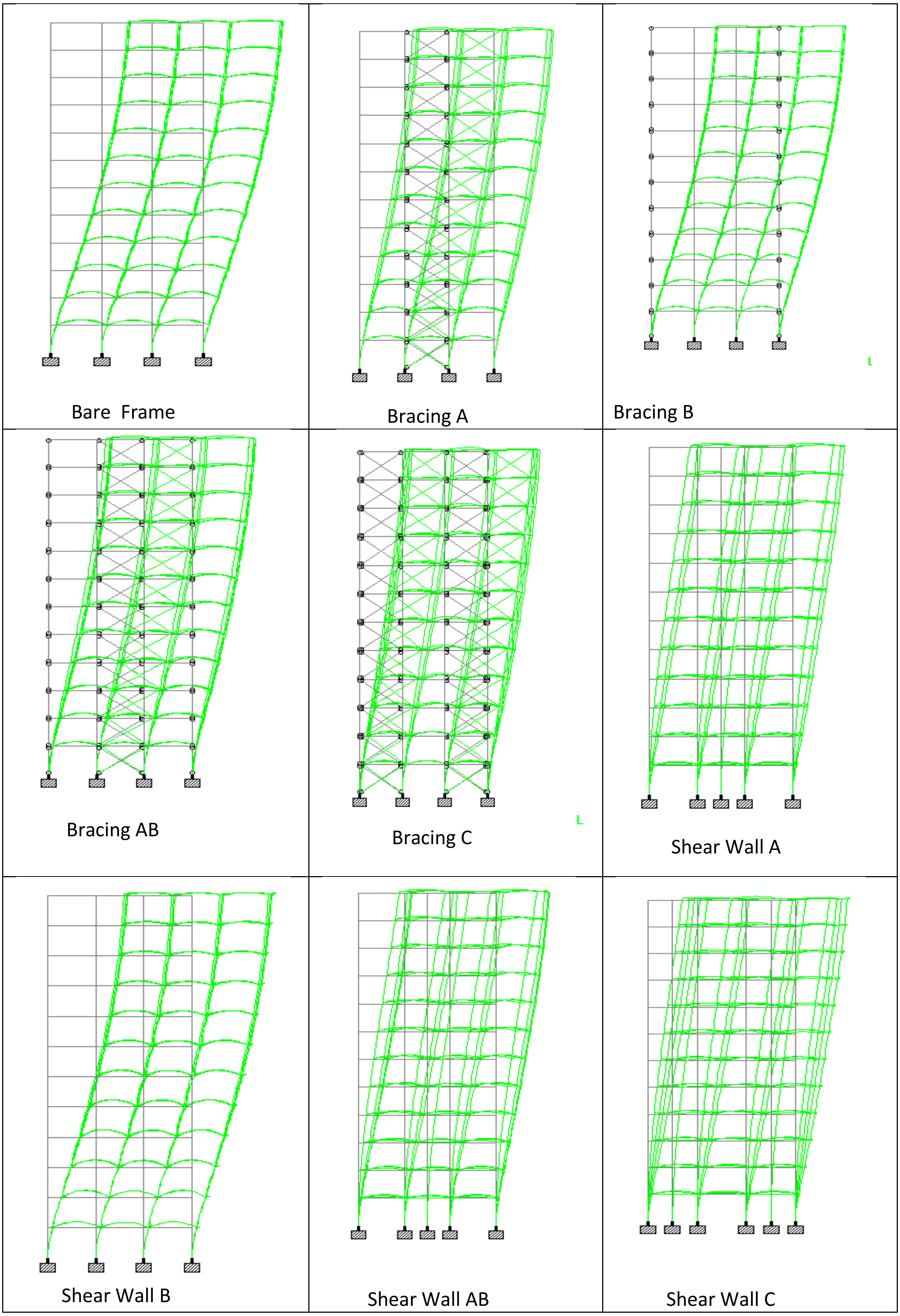


Fig 12 Staad Pro results for top-storey deflection in X direction

2.6 Comparison of Top-Storey Deflection for ground motion in Z- direction

Bracings were found to be ineffective in reducing top-storey deflection in Z direction in the frame. But there is remarkable reduction in top-storey deflection in Z direction due to shear wall. Reduction is more in case of Shear Wall C. For ground motion in Z- direction Shear Wall A is ineffective since in Shear Wall A case shear wall is present in X-direction not in Z-direction.

Table 19 below shows the top-storey deflection for each case, Fig 13. shows the variation in top-storey deflection in Z direction and Fig 14. shows the Staad Pro results for top-storey deflection.

Table 19. Top-Storey Drift for ground motion in Z- direction

Cases	**Top- Storey Deflection (mm)**
Bare Frame	125.648
Bracing A	125.499
Bracing B	126.884
Bracing AB	131.377
Bracing C	160.214
Shear Wall A	128.197
Shear Wall B	53.393
Shear Wall AB	54.055
Shear Wall C	58.939

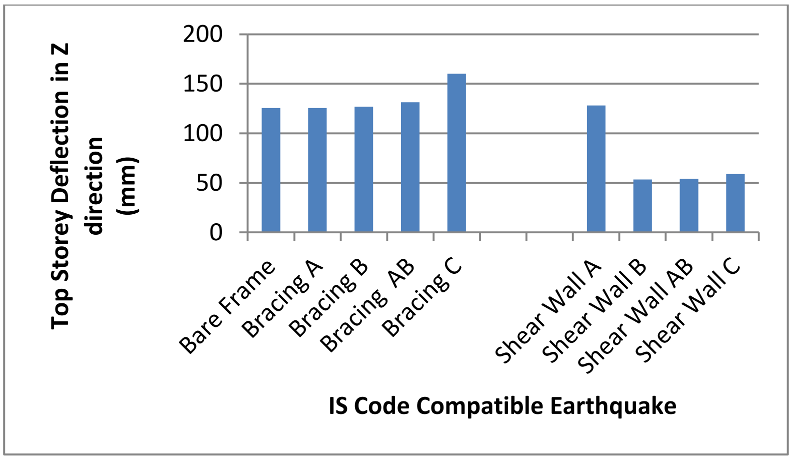
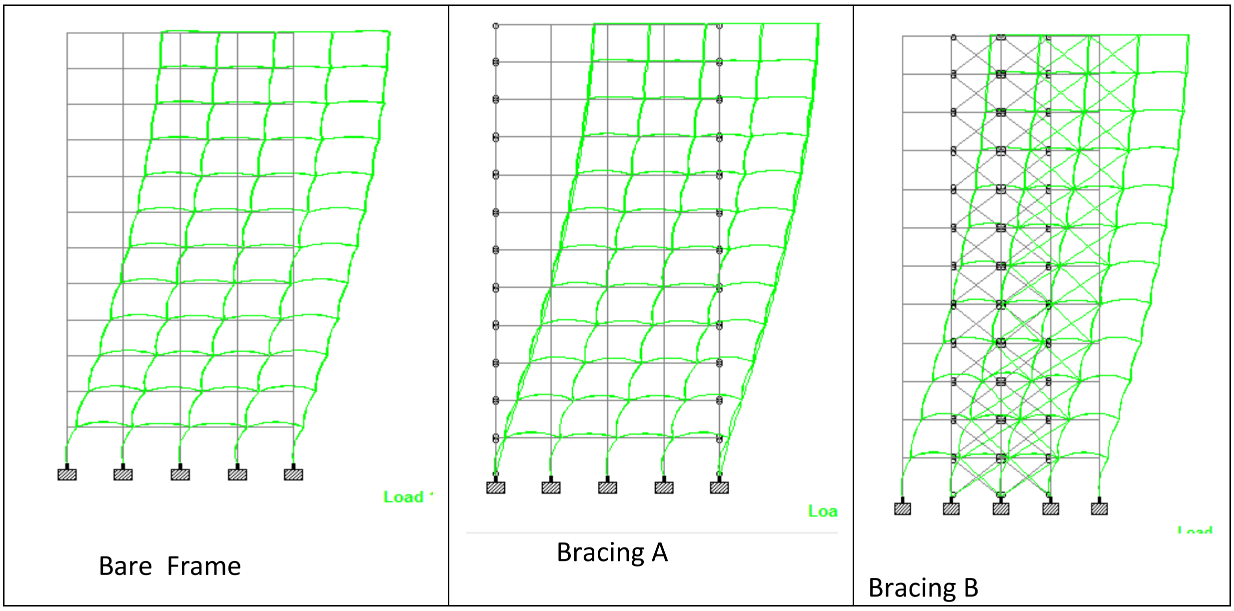
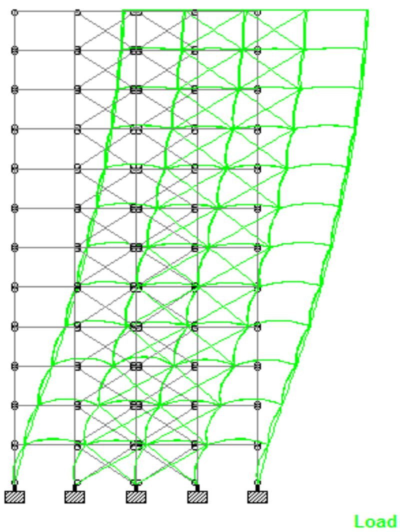


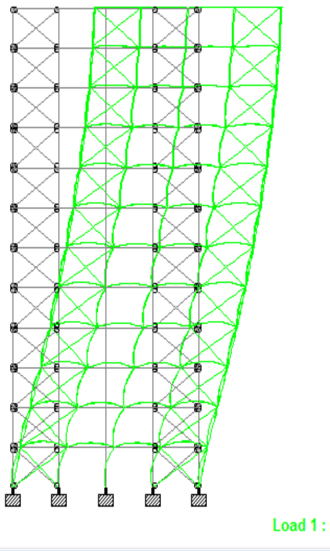
Fig 13. Variation of Top-Storey Deflection for ground motion in Z direction

Fig 14 Staad Pro results for top-storey deflection in Z direction

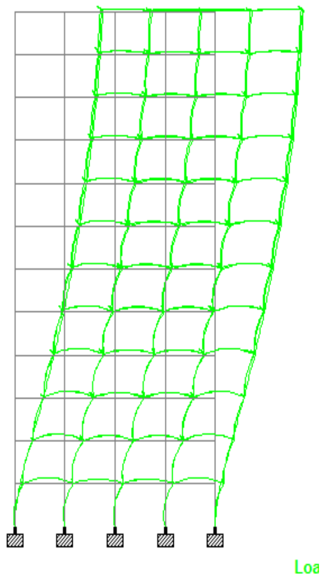




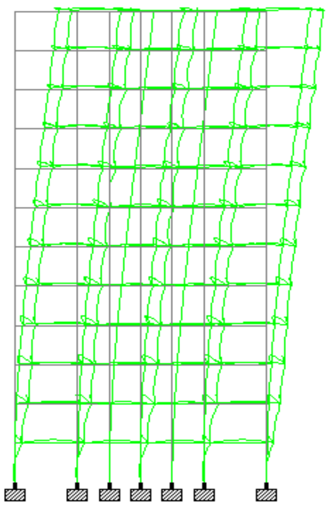
Bracing AB



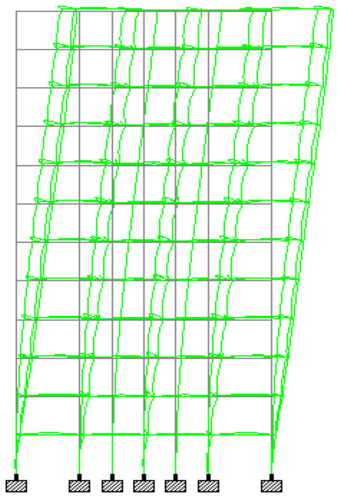
Bracing C



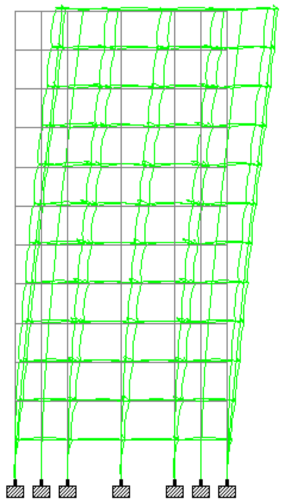
Shear Wall A



Shear Wall B



Shear Wall AB



Shear Wall C

3.Results and Comparison for Imperial Valley ground motion

Response Spectrum analysis of Imperial Valley ground motion was used for analysis of bare frame, bracing frame with all the cases and shear wall with all the cases for Imperial Valley ground motion was done and the results for base shear, inter-storey drifts and top-storey deflections were compared.

3.1 Comparison of Base Shear for ground motion in X-direction

The base shear was found to be increasing from bare frame to braced frame and is even more for frame with shear wall. In case of braced frame highest base shear is found in case of Bracing C in X-direction. In case of shear wall base shear is highest in case of Shear wall C in X-direction. Shear wall B shows the least base shear among all the shear wall cases because in case of Shear Wall B the frame is stiffened only along Y- direction and not along Z.

Table 20 shows the base shear for ground motion in X-direction for all the cases and Fig 13. Shows the variation of the base shear

Table 20. Base shear for ground motion in X-direction

Cases	Base Shear (kN)
Bare Frame	713.72
Bracing A	842.95
Bracing B	711.22
Bracing AB	842.74
Bracing C	891.88
Shear Wall A	982.39
Shear Wall B	783.76
Shear Wall AB	1103.23

Shear Wall C	1366.22

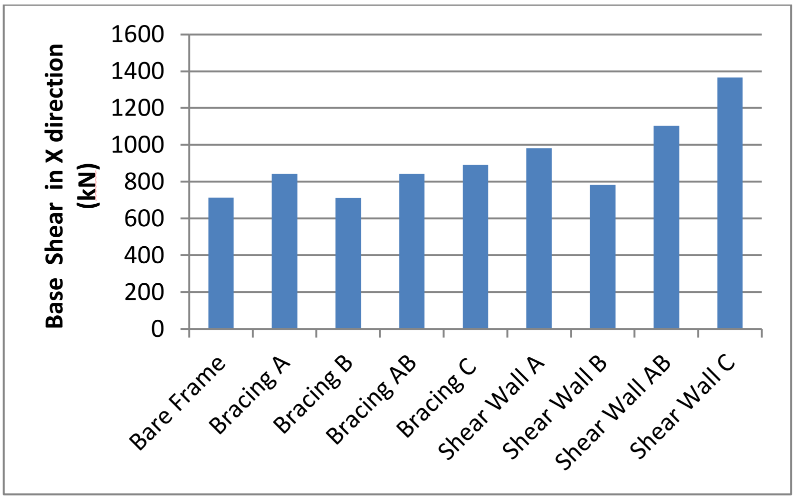


Fig 15. Variation of base shear for ground motion in X- direction

3.2Comparison of Base Shear for ground motion in Z-direction

Inter- storey drifts in bare frame was found to exceed this limit of 14mm. By using bracings it was found that there was no reduction in drift in Z direction but frame with shear wall showed remarkable reduction in the drift. Inter storey drift decreases remarkably in case of shear walls. For ground motion in Z-direction inter-storey drift is minimum in case Shear Wall C. Shear Wall B shows the least inter-store drift in Z-direction than Shear Wall A, because Shear Wall A is along Z direction only whereas Shear Wall A is along X direction only.

Table 21 shows the inter-storey drift for ground motion in Z-direction for all the cases. Fig 14. Shows the variation of inter-storey drift.

Table 21. Base shear for ground motion in Z-direction

Cases	Base Shear (kN)
Bare Frame	516.16
Bracing A	515.27
Bracing B	514.01
Bracing AB	514.03
Bracing C	515.4
Shear Wall A	551.64
Shear Wall B	623.94
Shear Wall AB	666.29
Shear Wall C	713.46

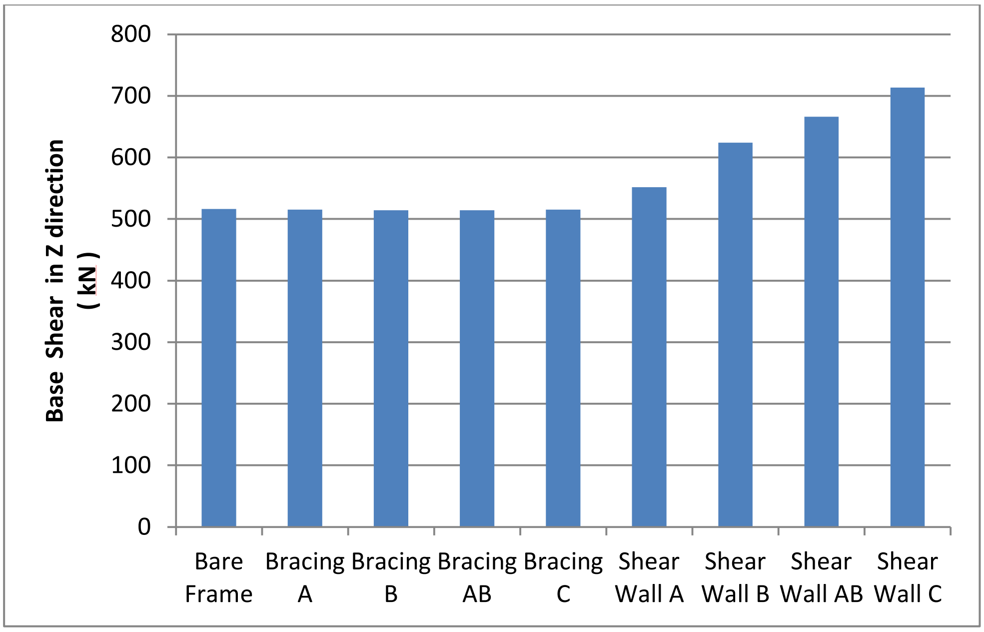


Fig 16. Variation of base shear for ground motion in Z- direction

3.2 Comparison of Inter-Storey Drift for ground motion in X-direction

The storey drift should be within 0.4% of storey height. For the building considered in this study the safe limit for storey drift is 14mm. Inter- storey drifts in bare frame was found to exceed this limit of 14mm. By using bracings and shear wall in the building the drift is found to be reduced. Inter storey drift decreases remarkably in case of shear walls. For ground motion in X-direction inter-storey drift is minimum in case of Bracing C and Shear Wall C. Shear Wall A shows the least inter-store drift in X-direction than Shear Wall B, because Shear Wall A is along X direction only whereas Shear Wall B is along Z direction only.

Table 22 shows the base shear for ground motion in X-direction for all the cases and Fig 15. Shows the variation of the base shear

Table 22. Inter-Storey Drift for ground motion in X- direction

Storey	Bare Frame	Bracing A	Bracing B	Bracing AB	Bracing C	Shear Wall A	Shear Wall B	Shear Wall AB	Shear Wall C
1	0	0	0	0	0	0	0	0	0
2	9.942	7.914	9.915	7.901	6.598	2.875	9.232	2.961	1.934
3	17.173	12.79	17.147	12.77	10.488	5.157	17.164	6.085	3.798
4	18.271	13.491	18.275	13.472	11.159	6.288	19.184	7.554	4.673
5	17.806	13.338	17.83	13.328	11.172	6.964	19.117	8.334	5.237
6	16.8	12.84	16.818	12.832	10.907	7.46	18.145	8.777	5.649
7	15.506	12.125	15.508	12.117	10.465	7.812	16.718	9.015	5.945
8	13.99	11.231	13.986	11.223	9.871	8.005	15.007	9.069	6.118
9	12.275	10.164	12.276	10.156	9.119	8.008	13.073	8.909	6.147
10	10.364	8.912	10.373	8.905	8.185	7.784	10.943	8.485	6.007
11	8.267	7.465	8.274	7.458	7.048	7.291	8.656	7.771	5.674
12	6.025	5.834	6.022	5.828	5.704	6.515	6.313	6.809	5.136
13	3.856	4.077	3.847	4.073	4.245	5.441	4.162	5.659	4.41

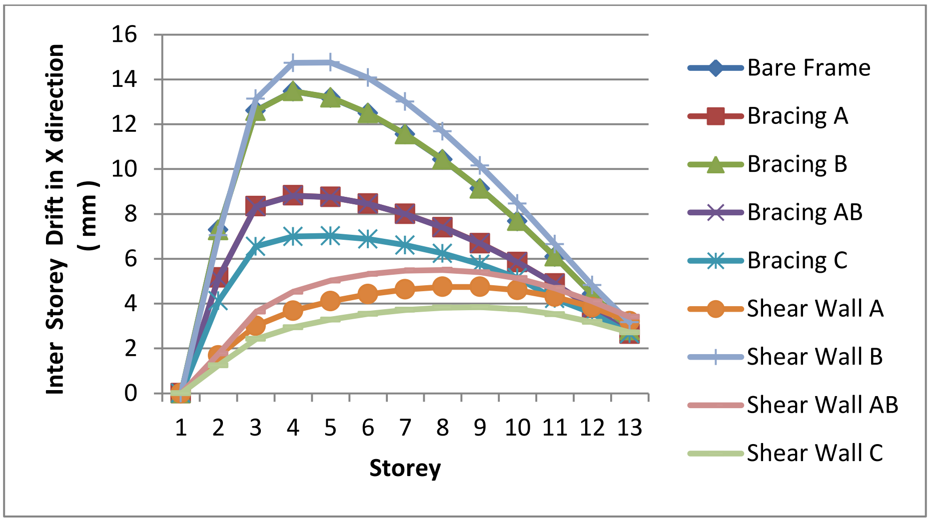


Fig 17. Variation of Inter-Storey Drift for ground motion in X direction

3.3 Comparison of Inter-Storey Drift for ground motion in Z-direction

Inter- storey drifts in bare frame was found to exceed this limit of 14mm. By using bracings it was found that there was no reduction in drift in Z direction but frame with shear wall showed remarkable reduction in the drift. Inter storey drift decreases remarkably in case of shear walls. For ground motion in Z-direction inter-storey drift is minimum in case Shear Wall C. Shear Wall B shows the least inter-store drift in Z-direction than Shear Wall A, because Shear Wall A is along Z direction only whereas Shear Wall A is along X direction only.

Table 23 shows the inter-storey drift for ground motion in Z-direction for all the cases. Fig 16. Shows the variation of inter-storey drift.

Table 23. Inter-Storey Drift for ground motion in Z- direction

Storey	Bare Frame	Bracing A	Bracing B	Bracing AB	Bracing C	Shear Wall A	Shear Wall B	Shear Wall AB	Shear Wall C
1	0	0	0	0	0	0	0	0	0
2	15.529	15.478	15.361	15.226	15.479	14.217	2.018	1.972	1.681
3	19.943	19.919	19.828	19.72	19.919	19.256	3.199	3.558	3.086
4	19.527	19.551	20.082	20.65	19.551	20.072	3.863	4.411	4.001
5	18.552	18.588	19.139	19.73	18.588	19.387	4.454	5	4.71
6	17.316	17.33	17.276	17.207	17.33	18.079	4.985	5.479	5.276

7	15.873	15.866	15.671	15.638	15.865	16.505	5.424	5.879	5.721
8	14.245	14.233	14.132	14.015	14.232	14.751	5.751	6.173	6.048
9	12.437	12.435	12.344	12.236	12.434	12.823	5.94	6.316	6.236
10	10.442	10.452	10.373	10.279	10.451	10.714	5.956	6.261	6.256
11	8.253	8.26	8.197	8.122	8.259	8.433	5.764	5.972	6.082
12	5.866	5.858	5.815	5.762	5.857	6.027	5.312	5.441	5.685
13	3.371	3.357	3.336	3.309	3.355	3.603	4.512	4.644	4.984

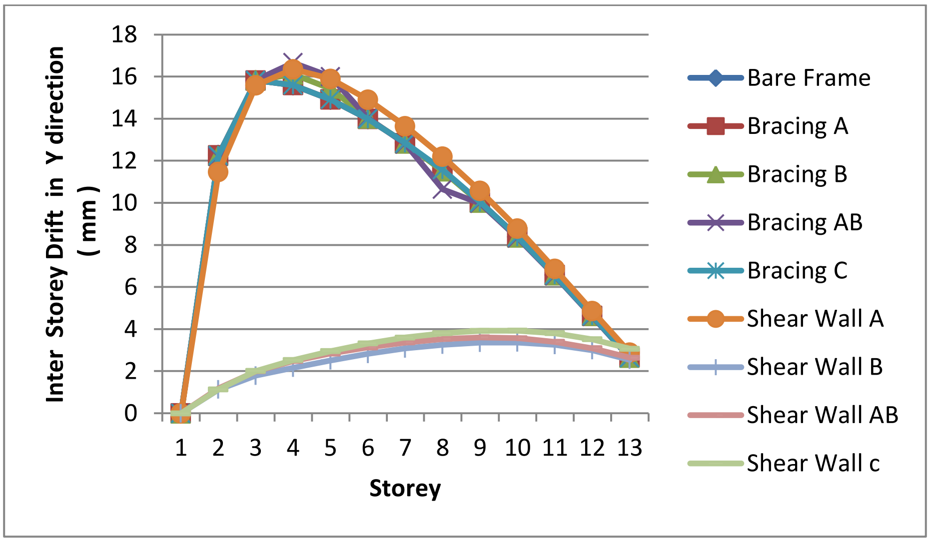


Fig 18. Variation of Inter-Storey Drift for ground motion in Z direction

3.4 Comparison of Top-Storey Deflection for ground motion in X- direction

There is reduction in top-storey deflection in the frame due to bracing and shear wall. Reduction is more in case of Bracing C and Shear Wall C. For ground motion in X- direction Shear Wall B is ineffective since in Shear Wall B case shear wall is present in Z-direction not in X-direction.

Table 23 below shows the top-storey deflection for each case, Fig 17. shows the variation in top-storey deflection in X direction and Fig.18 shows the Staad Pro results for top-storey deflection.

Table 24. Top-Storey Drift for ground motion in X- direction

Cases	Top- Storey Deflection (mm)
Bare Frame	109.59
Bracing A	75.391
Bracing B	109.647
Bracing AB	75.326
Bracing C	61.633
Shear Wall A	42.566
Shear Wall B	118.857
Shear Wall AB	47.281
Shear Wall C	32.066

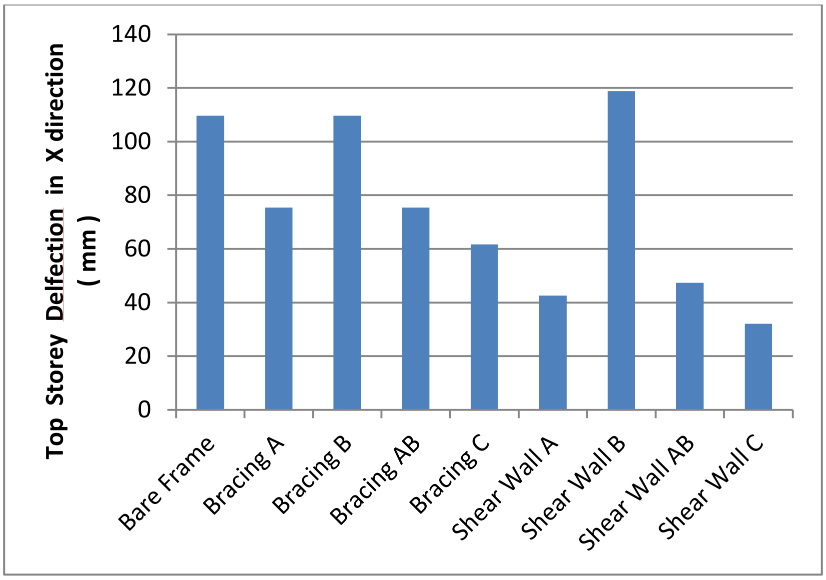
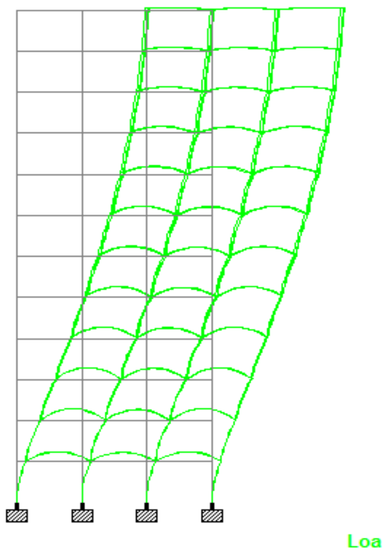
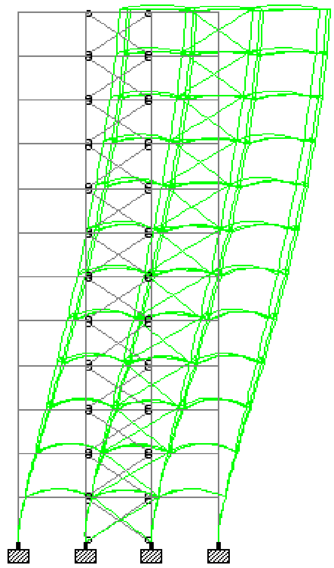


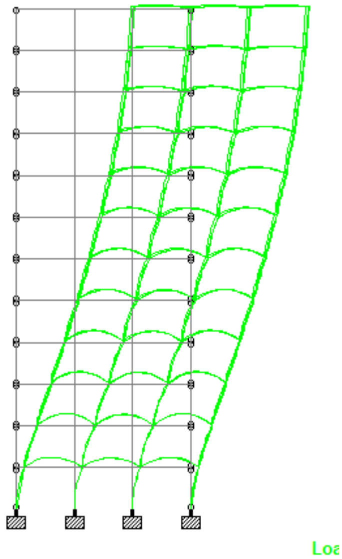
Fig 19. Variation of Top-Storey Deflection for ground motion in X direction



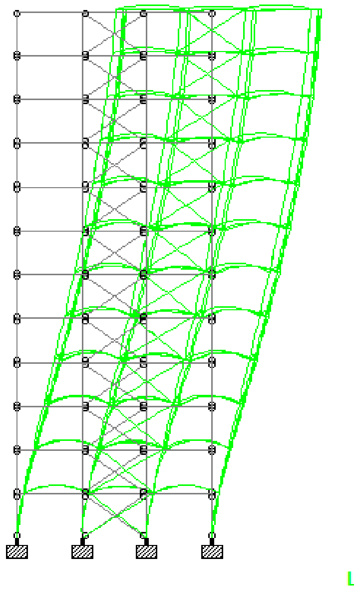
Bare Frame



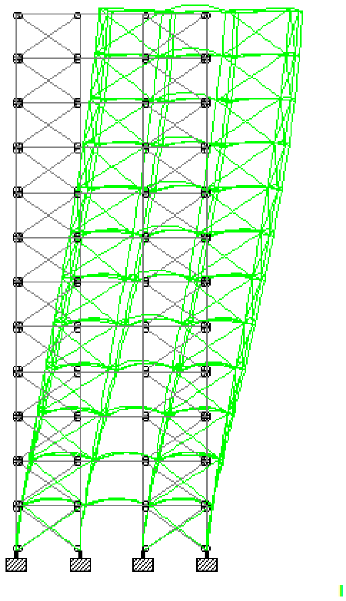
Bracing A



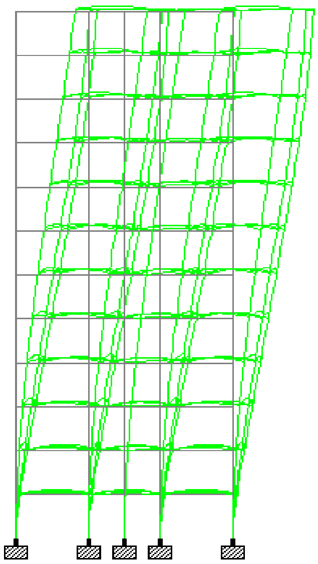
Bracing B



Bracing AB



Bracing C



Shear Wall A

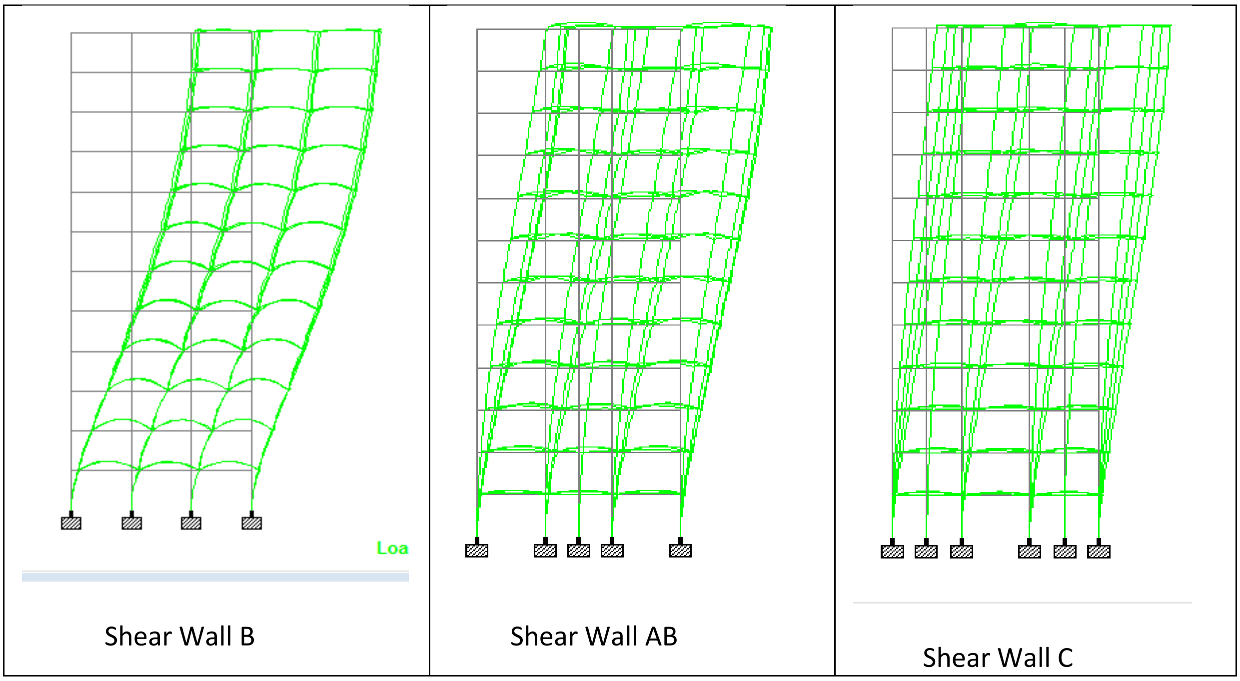


Fig 20. Staad Pro results for top-storey deflection in X direction

3.4 Comparison of Top-Storey Deflection for ground motion in Z- direction

Bracings were found to be ineffective in reducing top-storey deflection in Z direction in the frame. But there is remarkable reduction in top-storey deflection in Z direction due to shear wall. Reduction is more in case of Shear Wall C. For ground motion in Z- direction Shear Wall A is ineffective since in Shear Wall A case shear wall is present in X-direction not in Z-direction.

Table 25 below shows the top-storey deflection for each case, Fig 19. shows the variation in top-storey deflection in Z direction and Fig 20. shows the Staad Pro results for top-storey deflection.

Table 25. Top-Storey Drift for ground motion in Z- direction

Cases	Top- Storey Deflection (mm)
Bare Frame	128.323
Bracing A	128.308
Bracing B	129.24
Bracing AB	130.153
Bracing C	128.292
Shear Wall A	132.628
Shear Wall B	29.286
Shear Wall AB	30.871
Shear Wall C	34.449

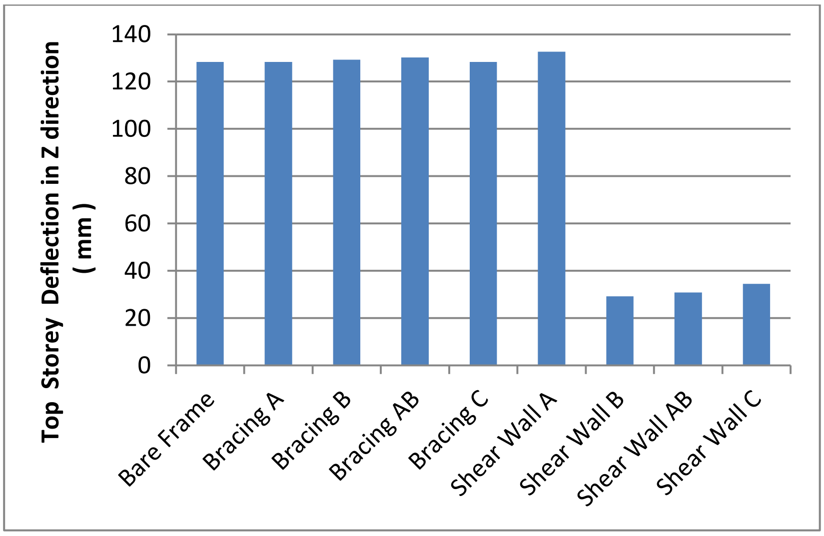
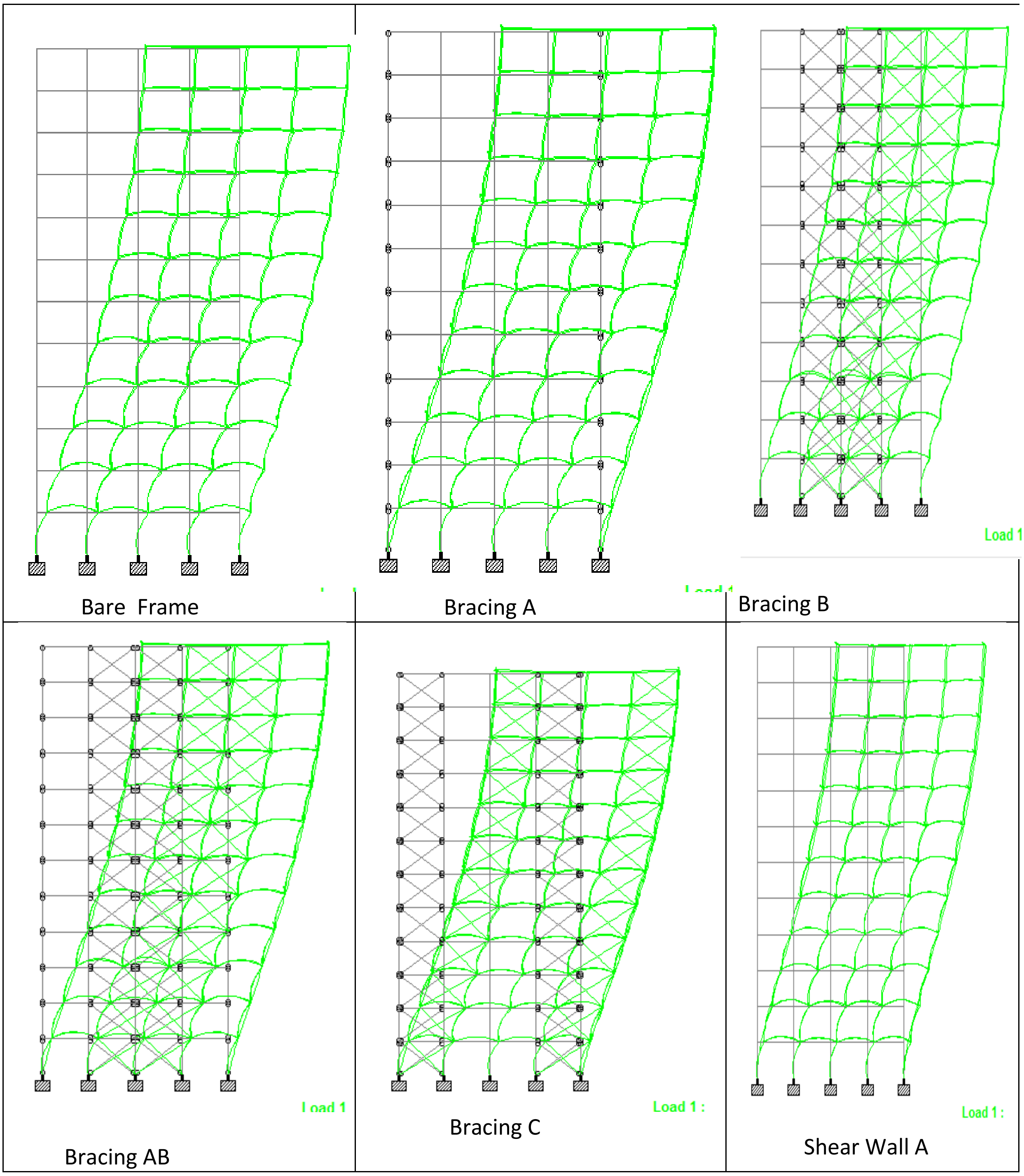
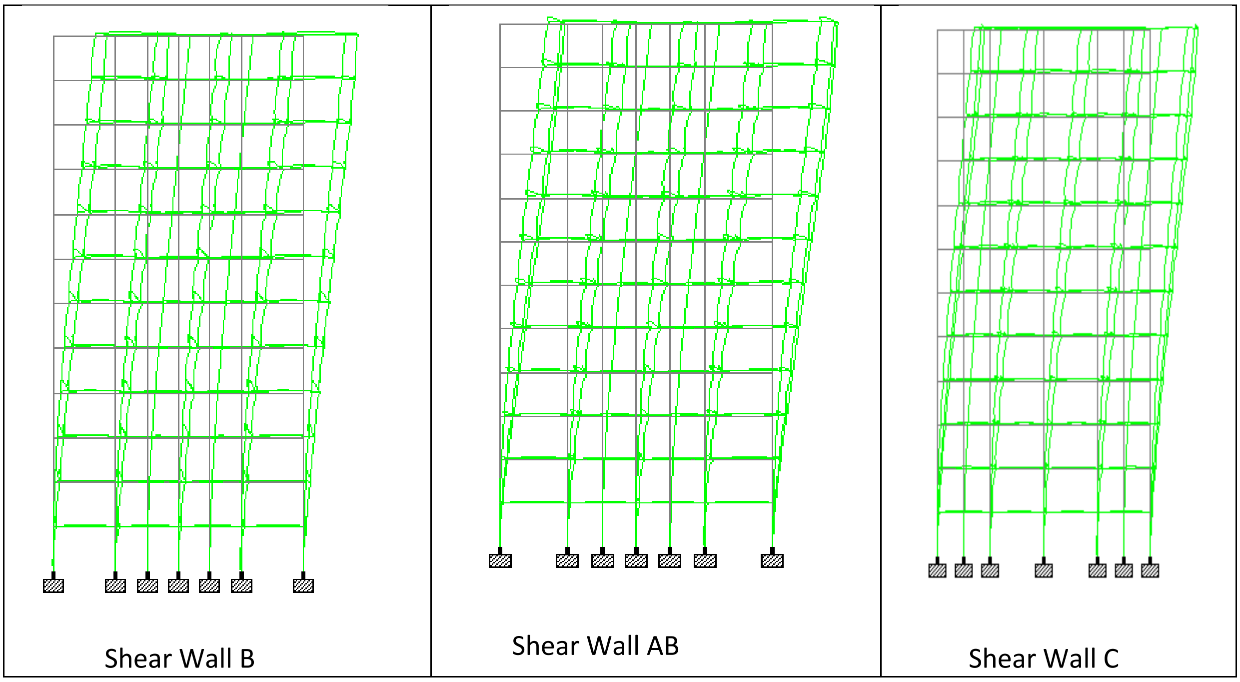


Fig 21. Variation of Top-Storey Deflection for ground motion in Z direction

Fig 22 Staad Pro results for top-storey deflection in Z direction





4 Results and Comparison for San Francisco ground motion

Response Spectrum analysis of San Francisco ground motion was used for analysis of bare frame, bracing frame with all the cases and shear wall with all the cases for San Francisco ground motion and the results for base shear, inter-storey drifts and top-storey deflections were compared.

4.1 Comparison of Base Shear for ground motion in X-direction

The base shear was found to be increasing from bare frame to braced frame and is even more for frame with shear wall. In case of braced frame highest base shear is found in case of Bracing C in X-direction. In case of shear wall base shear is highest in case of Shear wall C in X-direction. Shear wall B shows the least base shear among all the shear wall cases because in case of Shear Wall B the frame is stiffened only along Y- direction and not along Z.

Table 26 shows the base shear for ground motion in X-direction for all the cases and Fig 21. Shows the variation of the base shear

Table 26. Base shear for ground motion in X-direction

Cases	Base Shear (kN)
Bare Frame	522.35
Bracing A	594.98
Bracing B	521.09
Bracing AB	549.96
Bracing C	558.12
Shear Wall A	577.41
Shear Wall B	597.17
Shear Wall AB	663.02
Shear Wall C	711.02

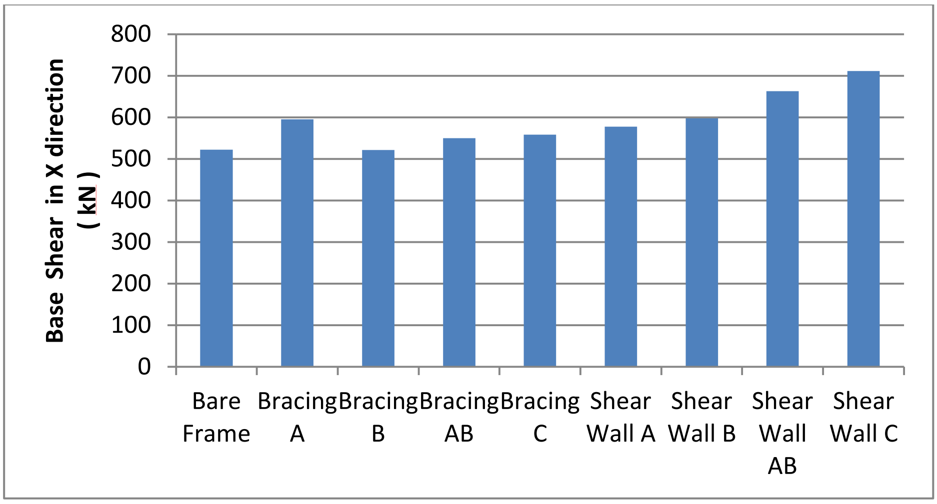


Fig 23. Variation of base shear for ground motion in X- direction

4.2 Comparison of Base Shear for ground motion in Z-direction

Inter- storey drifts in bare frame was found to exceed this limit of 14mm. By using bracings it was found that there was no reduction in drift in Z direction but frame with shear wall showed remarkable reduction in the drift. Inter storey drift decreases remarkably in case of shear walls. For ground motion in Z-direction inter-storey drift is minimum in case Shear Wall C. Shear Wall B shows the least inter-store drift in Z-direction than Shear Wall A, because Shear Wall A is along Z direction only whereas Shear Wall A is along X direction only.
Table 27 shows the inter-storey drift for ground motion in Z-direction for all the cases. Fig 22. Shows the variation of inter-storey drift.

Table 27. Base shear for ground motion in Z-direction

Cases	Base Shear (kN)
Bare Frame	516.16
Bracing A	515.27
Bracing B	514.01
Bracing AB	514.03
Bracing C	515.4
Shear Wall A	551.64
Shear Wall B	623.94
Shear Wall AB	666.29
Shear Wall C	713.46

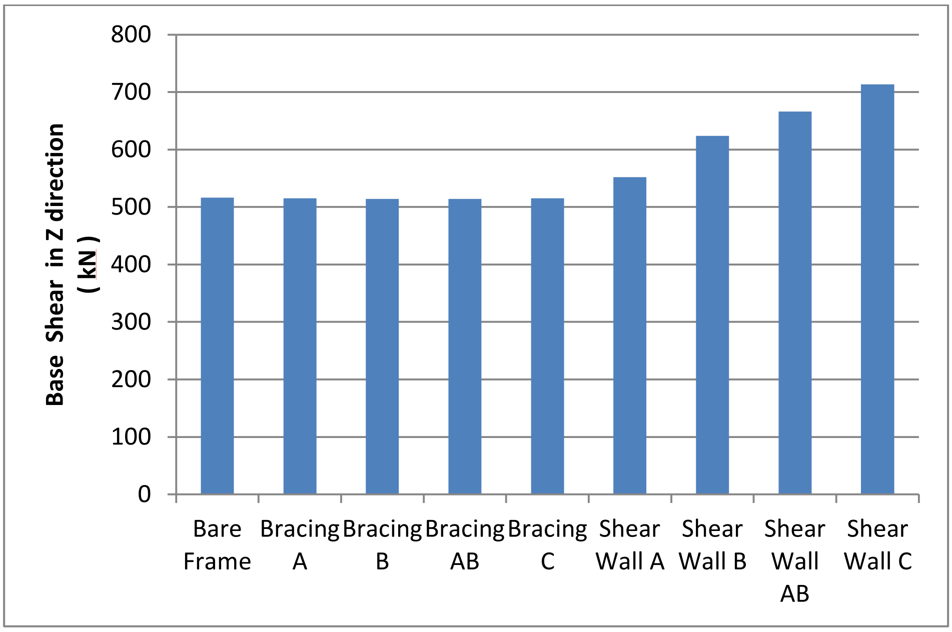


Fig 24. Variation of base shear for ground motion in Z- direction

4.3 Comparison of Inter-Storey Drift for ground motion in X-direction

The storey drift should be within 0.4% of storey height. For the building considered in this study the safe limit for storey drift is 14mm. Inter- storey drifts in bare frame was found to exceed this limit of 14mm. By using bracings and shear wall in the building the drift is found to be reduced. Inter storey drift decreases remarkably in case of shear walls. For ground motion in X-direction inter-storey drift is minimum in case of Bracing C and Shear Wall C. Shear Wall A shows the least inter-store drift in X-direction than Shear Wall B, because Shear Wall A is along X direction only whereas Shear Wall B is along Z direction only.

Table 28 shows the base shear for ground motion in X-direction for all the cases and Fig 23. Shows the variation of the base shear

Table 28. Inter-Storey Drift for ground motion in X- direction

Storey	Bare Frame	Bracing A	Bracing B	Bracing AB	Bracing C	Shear Wall A	Shear Wall B	Shear Wall AB	Shear Wall C
1	0	0	0	0	0	0	0	0	0
2	7.285	5.158	7.272	5.149	4.117	1.678	7.048	1.766	1.246
3	12.608	8.345	12.598	8.331	6.552	3.011	13.129	3.63	2.419
4	13.463	8.825	13.47	8.812	6.989	3.685	14.732	4.522	2.943
5	13.181	8.753	13.196	8.745	7.021	4.106	14.755	5.02	3.282
6	12.487	8.452	12.498	8.444	6.874	4.419	14.071	5.315	3.538
7	11.551	7.996	11.555	7.989	6.607	4.634	13.001	5.471	3.719
8	10.423	7.407	10.426	7.401	6.233	4.745	11.676	5.501	3.822
9	9.128	6.693	9.131	6.687	5.749	4.742	10.151	5.397	3.838
10	7.678	5.853	7.684	5.847	5.147	4.601	8.46	5.129	3.746
11	6.093	4.887	6.098	4.882	4.22	4.301	6.65	4.685	3.528
12	4.417	3.81	4.418	3.806	3.571	3.839	4.818	4.098	3.178
13	2.818	2.659	2.815	2.657	2.656	3.208	3.16	3.406	2.716

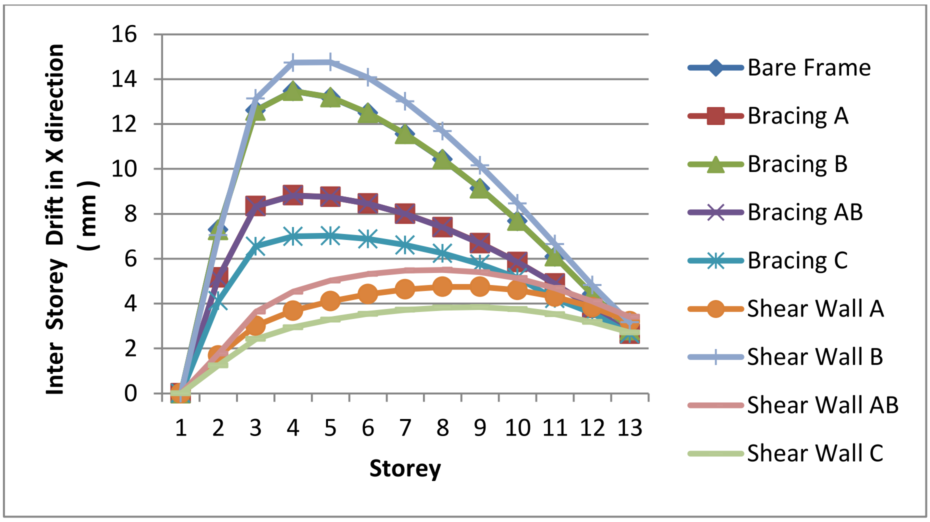


Fig 25. Variation of Inter-Storey Drift for ground motion in X direction

4.4 Comparison of Inter-Storey Drift for ground motion in Z-direction

Inter- storey drifts in bare frame was found to exceed this limit of 14mm. By using bracings it was found that there was no reduction in drift in Z direction but frame with shear wall showed remarkable reduction in the drift. Inter storey drift decreases remarkably in case of shear walls. For ground motion in Z-direction inter-storey drift is minimum in case Shear Wall C. Shear Wall B shows the least inter-store drift in Z-direction than Shear Wall A, because Shear Wall A is along Z direction only whereas Shear Wall A is along X direction only.

Table 29 shows the inter-storey drift for ground motion in Z-direction for all the cases. Fig 24. Shows the variation of inter-storey drift.

Table 29. Inter-Storey Drift for ground motion in Z- direction

Storey	Bare Frame	Bracing A	Bracing B	Bracing AB	Bracing C	Shear Wall A	Shear Wall B	Shear Wall AB	Shear Wall C
1	0	0	0	0	0	0	0	0	0
2	12.276	12.257	12.229	12.192	12.257	11.471	1.126	1.18	1.134
3	15.823	15.813	15.826	15.831	15.813	15.591	1.787	1.996	2.007
4	15.587	15.596	16.107	16.661	15.595	16.346	2.165	2.479	2.525
5	14.903	14.915	15.432	15.999	14.915	15.893	2.511	2.84	2.951
6	13.977	13.981	14.009	14.03	13.981	14.902	2.82	3.128	3.314
7	12.844	12.841	12.822	12.792	12.84	13.645	3.078	3.36	3.6
8	11.524	11.517	11.497	10.64	11.571	12.195	3.253	3.527	3.804
9	10.03	10.028	10.007	9.974	10.027	10.569	3.357	3.603	3.919
10	8.374	8.377	8.357	8.327	8.375	8.779	3.363	3.566	3.924
11	6.57	6.572	6.556	6.532	6.571	6.855	3.25	3.395	3.8
12	4.635	4.631	4.621	4.604	4.63	4.857	2.995	3.09	3.517
13	2.651	2.645	2.642	2.635	2.643	2.885	2.545	2.64	3.065

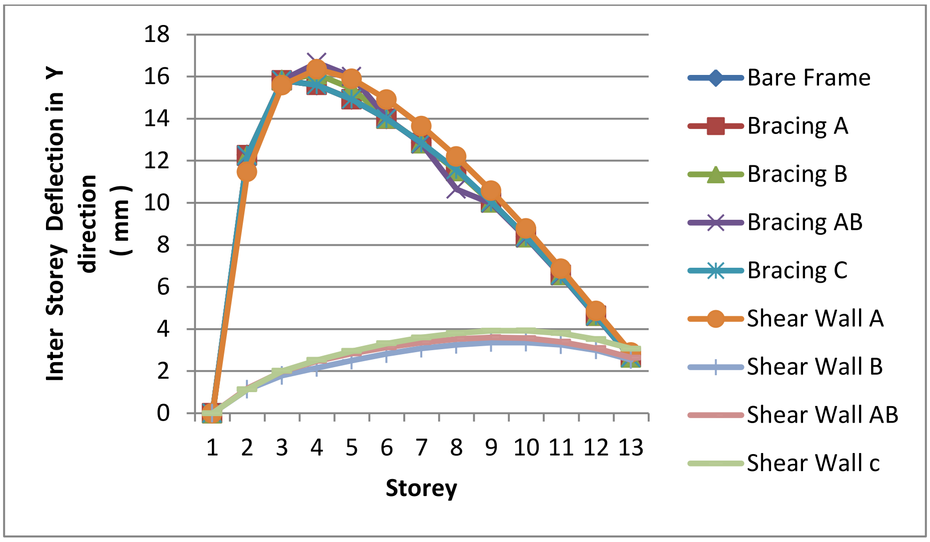


Fig 26. Variation of Inter-Storey Drift for ground motion in Z direction

4.5 Comparison of Top-Storey Deflection for ground motion in X- direction

There is reduction in top-storey deflection in the frame due to bracing and shear wall. Reduction is more in case of Bracing C and Shear Wall C. For ground motion in X-direction Shear Wall B is ineffective since in Shear Wall B case shear wall is present in Z-direction not in X-direction.

Table 30 below shows the top-storey deflection for each case, Fig 25. shows the variation in top-storey deflection in X direction and Fig.26 shows the Staad Pro results for top-storey deflection.

Table 30. Top-Storey Drift for ground motion in X- direction

Cases	Top- Storey Deflection (mm)
Bare Frame	109.59
Bracing A	75.391

Bracing B	109.647
Bracing AB	75.326
Bracing C	61.633
Shear Wall A	42.566
Shear Wall B	118.857
Shear Wall AB	47.281
Shear Wall C	32.066

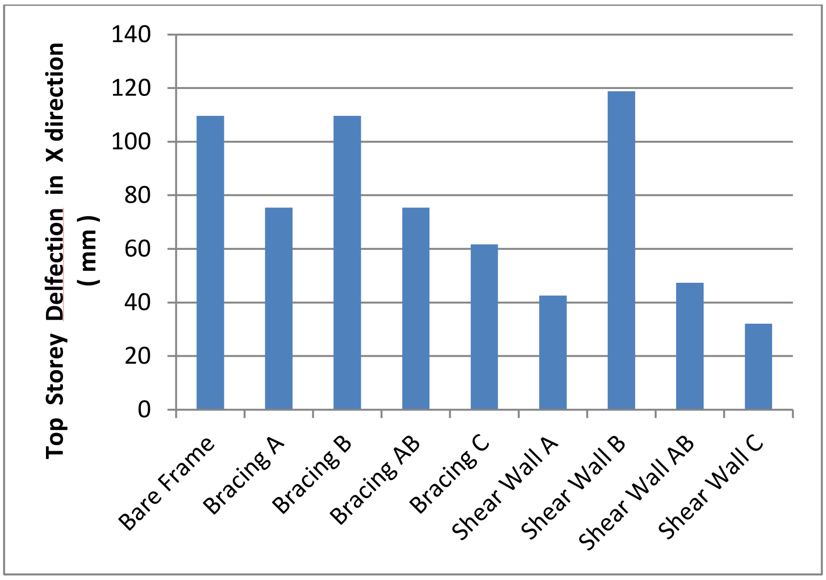
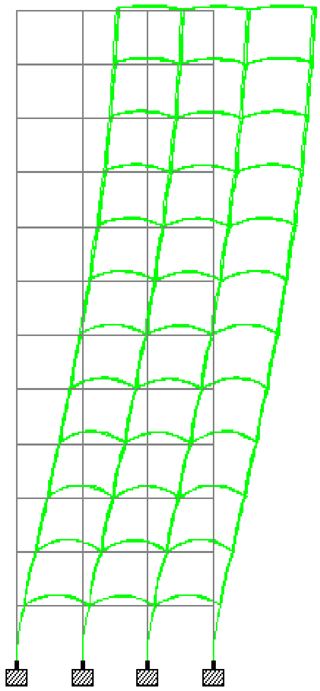
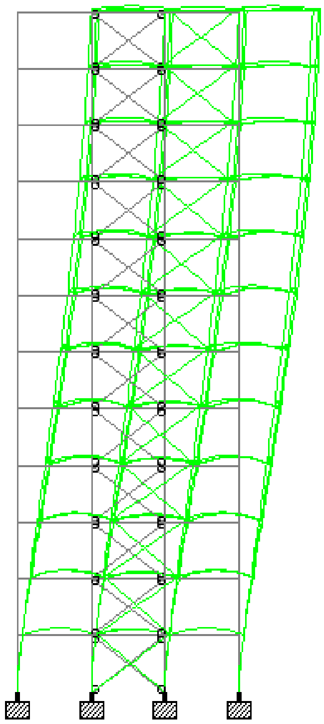


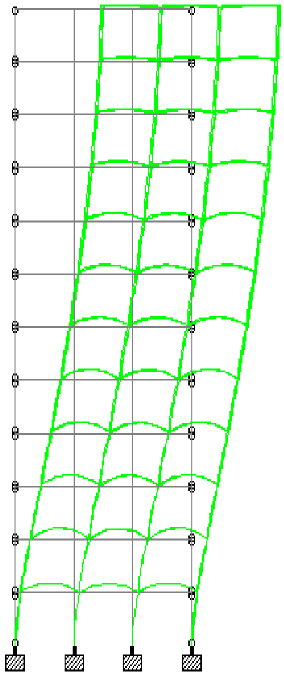
Fig 27. Variation of Top-Storey Deflection for ground motion in X direction



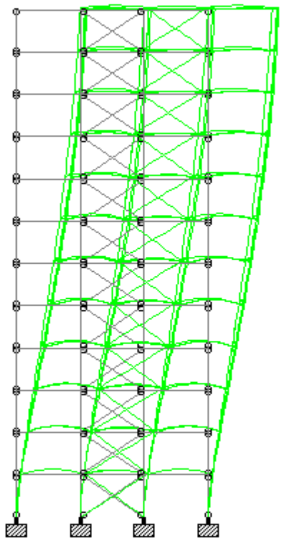
Bare Frame



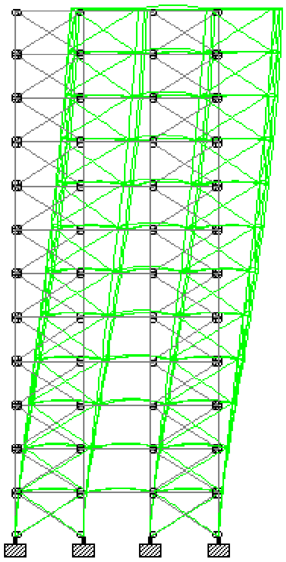
Bracing A



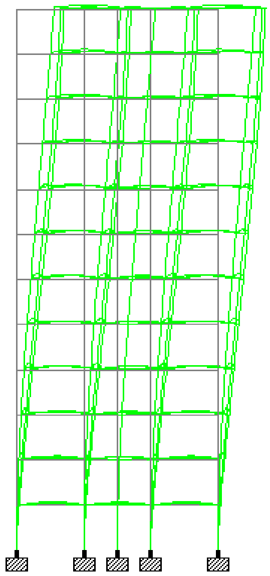
Bracing B



Bracing AB



Bracing C



Shear Wall A

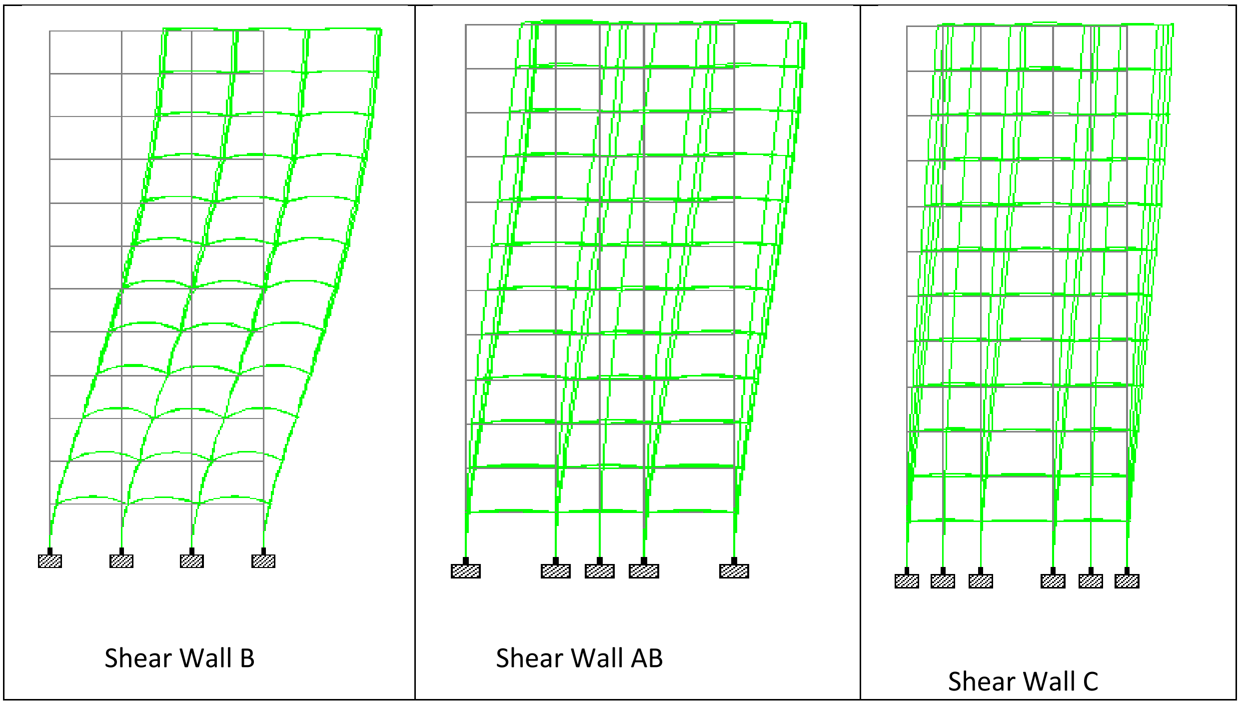


Fig 28. Staad Pro results for top-storey deflection in X direction

4.6 Comparison of Top-Storey Deflection for ground motion in Z- direction

Bracings were found to be ineffective in reducing top-storey deflection in Z direction in the frame. But there is remarkable reduction in top-storey deflection in Z direction due to shear wall. Reduction is more in case of Shear Wall C. For ground motion in Z- direction Shear Wall A is ineffective since in Shear Wall A case shear wall is present in X-direction not in Z-direction.

Table 31 below shows the top-storey deflection for each case, Fig 27. shows the variation in top-storey deflection in Z direction and Fig 28. shows the Staad Pro results for top-storey deflection.

Table 31. Top-Storey Drift for ground motion in Z- direction

Cases	Top- Storey Deflection (mm)
Bare Frame	128.323
Bracing A	128.308
Bracing B	129.24
Bracing AB	130.153
Bracing C	128.292
Shear Wall A	132.628
Shear Wall B	29.286
Shear Wall AB	30.871
Shear Wall C	34.449

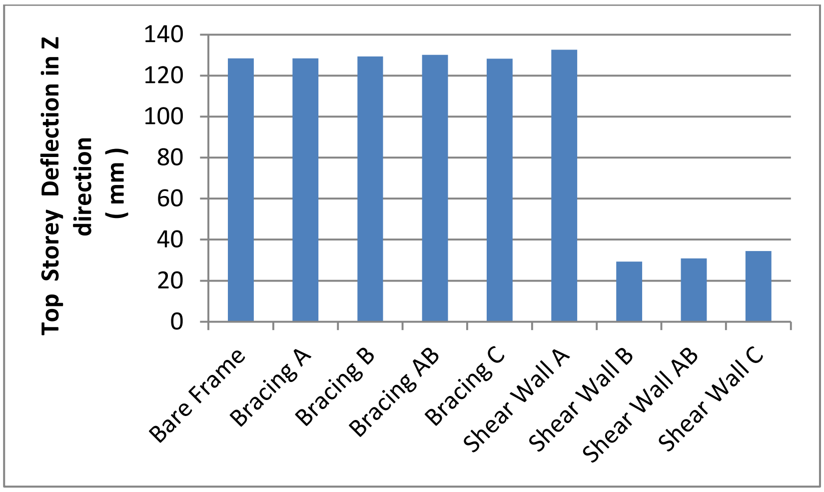
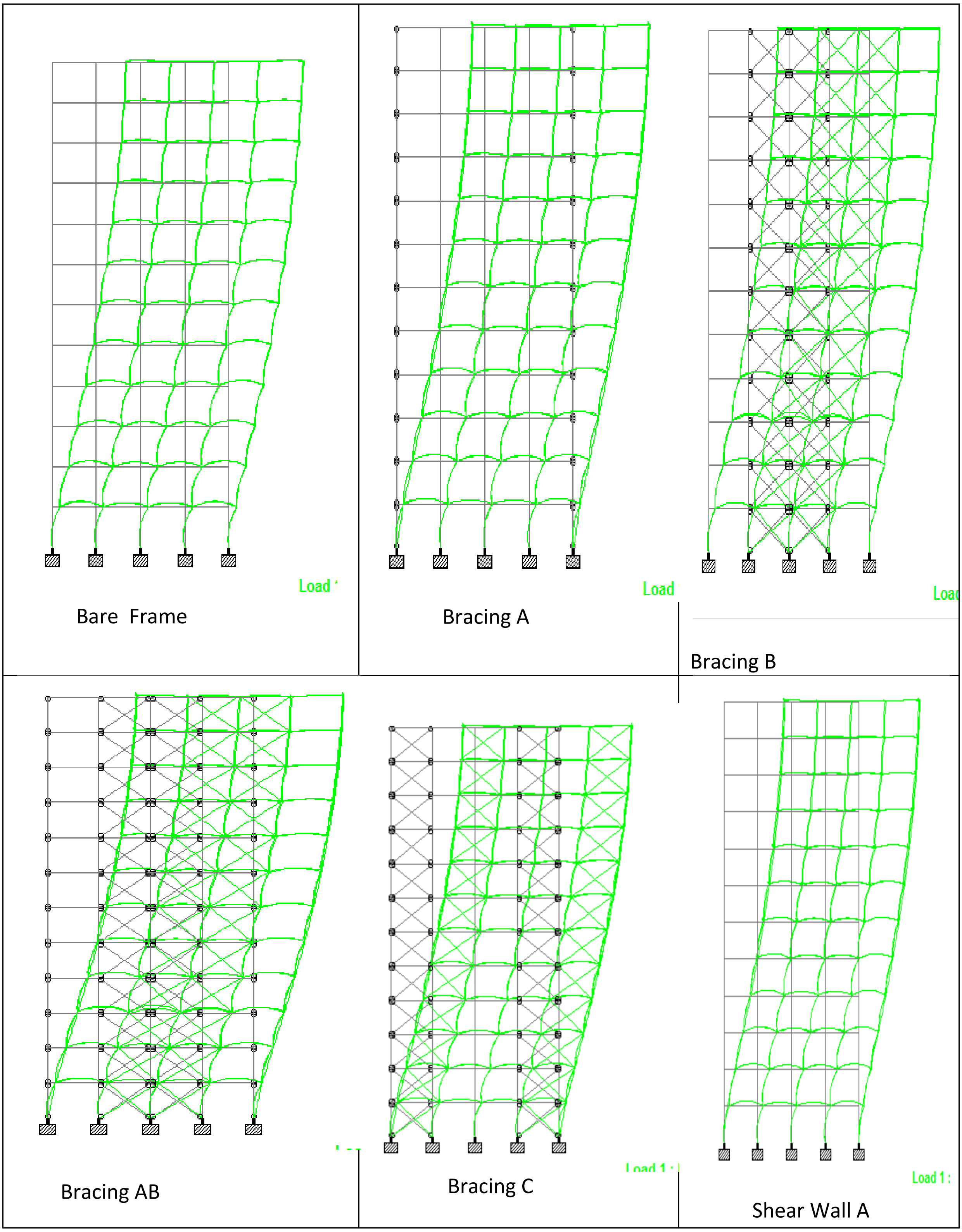
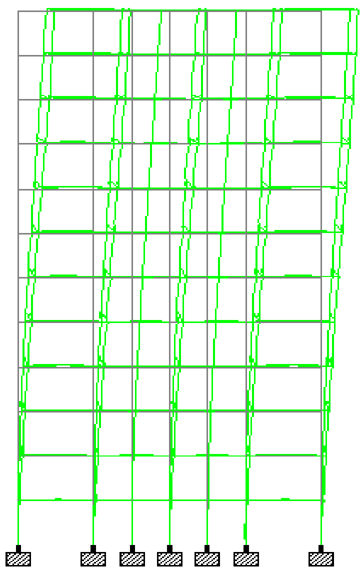


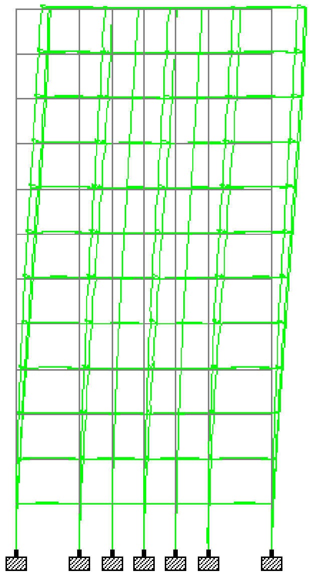
Fig 29. Variation of Top-Storey Deflection for ground motion in Z direction

Fig 28. Staad Pro results for top-storey deflection in Z direction

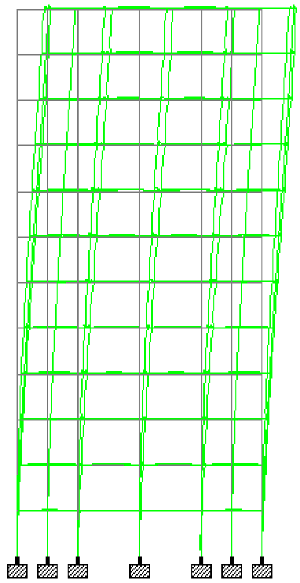




Shear Wall B



Shear Wall AB



Shear Wall C

CONCLUSION

This project work was a small effort towards perceiving the how introducing bracing or a shear wall in a building can make in difference in protecting the building in earthquakes. Almost all the buildings in India are RC frame, and earthquake tremors are felt every now a then in some or the other part of the country. Hence through this project it was tried to appreciate the effectiveness and role of this small extra structural elements that can save both life and property, at least for most of the earthquakes.

The following conclusions were drawn at the end of the study :

- There is a gradual reduction in time periods of the bracing and shear wall systems from the time period of bare frame, indicating increase in stiffness.
- Time Period in case of Shear Wall C is the highest, hence is the most stiff and better option for strengthening the structure.
- Base Shear produced in the Bare Frame is maximum for Imperial Valley Earthquake.
- In case of bracing system, Bracing System C (with braces at the corners) are the most effective one than other bracing systems, effectively reducing top-storey drift and inter storey drifts in both X- and Z- directions.
- There is hardly any reduction in drift along Z- direction due to Bracing B, for all the ground motions.
- Shear Wall A is effective in reducing drifts along X- direction only, and Shear Wall B is effective in reducing drifts along Z- direction only, for all the ground motions.
- Above all Shear Wall C is the best in all the stiffening cases considered

REFERENCES

- [1] Google images for Steel Bracing in RC building.
- [2] Google images for Steel Bracing in RC building.
- [3] Google images for Shear Wall.
- IS 1893 (Part 1) : 2002 Indian Standard *Criteria for Earthquake Resistant Design of Structures*, Part 1 General Provisions and Buildings, (Fifth Revision).
- Anil K. Chopra [2003] *"Dynamics of Structures, Theory and Applications to Earthquake Engineering" (Prentice Hall of India Private Limited).*
- Chandurkar P. P, Dr. Pajgade P. S. (2013). "Seismic Analysis of RCC Building with and Without Shear Wall." , **International Journal of Modern Engineering Research (IJMER) (2249-6645)**.
- Chavan Krishnaraj R. ,Jadhav H.S. (2014). "Seismic Response of RC Building With Different Arrangement of Steel Bracing System.", **International Journal of engineering Research and Applications (2248-9622)**.
- Esmaili O. et al. (2008). "**Study of Structural RC Shear Wall System in a 56-Storey RC Tall Building.**", The 14th World Conference on Earthquake Engineering October 12-17, 2008 , Beijing, China.
- Akbari R.et al. (2014). "Seismic Fragility Assessment of Steel X-Braced and Chevron- Braced RC Frames.", **Asian Journal of Civil Engineering (BHRC), VOL-16 No.1 .**
- Kappos Andreas J., Manafpour Alireza (2000). "Seismic Design of R/C Buildings with the aid of advanced analytical techniques." **Engineering Structures 23 (2001) 319-332**.
- Yamada M. et al. " Multistorey Bracing Systems of Reinforced Concrete and Steel – Rigid Frames Subjected To Horizontal Loads- Proposition of Total Evaluation on the Aseismic Capacity for Design."
- Viswanath K.G. et al.(2010). "Seismic Analysis of Steel Braced Reinforced Concrete Frames." **International Journal of Civil & Structural Engineering (0976-4399)**.